An Assessment of a Stacked Shale Gas Play and the Effect on Forest Fragmentation in Pennsylvania

MGIS Capstone Project
Ben Ogle, GISP

Advisor: Dr. Patrick Drohan
GEOG596B

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PennState

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Geospatial data
from the field to the end user

Personal Background

- Working as GIS Analyst in the oil & gas industry for 6+ years
- GIS Analyst III at CNX Resources Corp.
  - GIS application development
  - Mobile GIS solutions
- Undergraduate Adjunct GIS Instructor at SUNY Empire State College.
- Accepted into the Penn State MGIS program in 2015, and I will graduate in December.

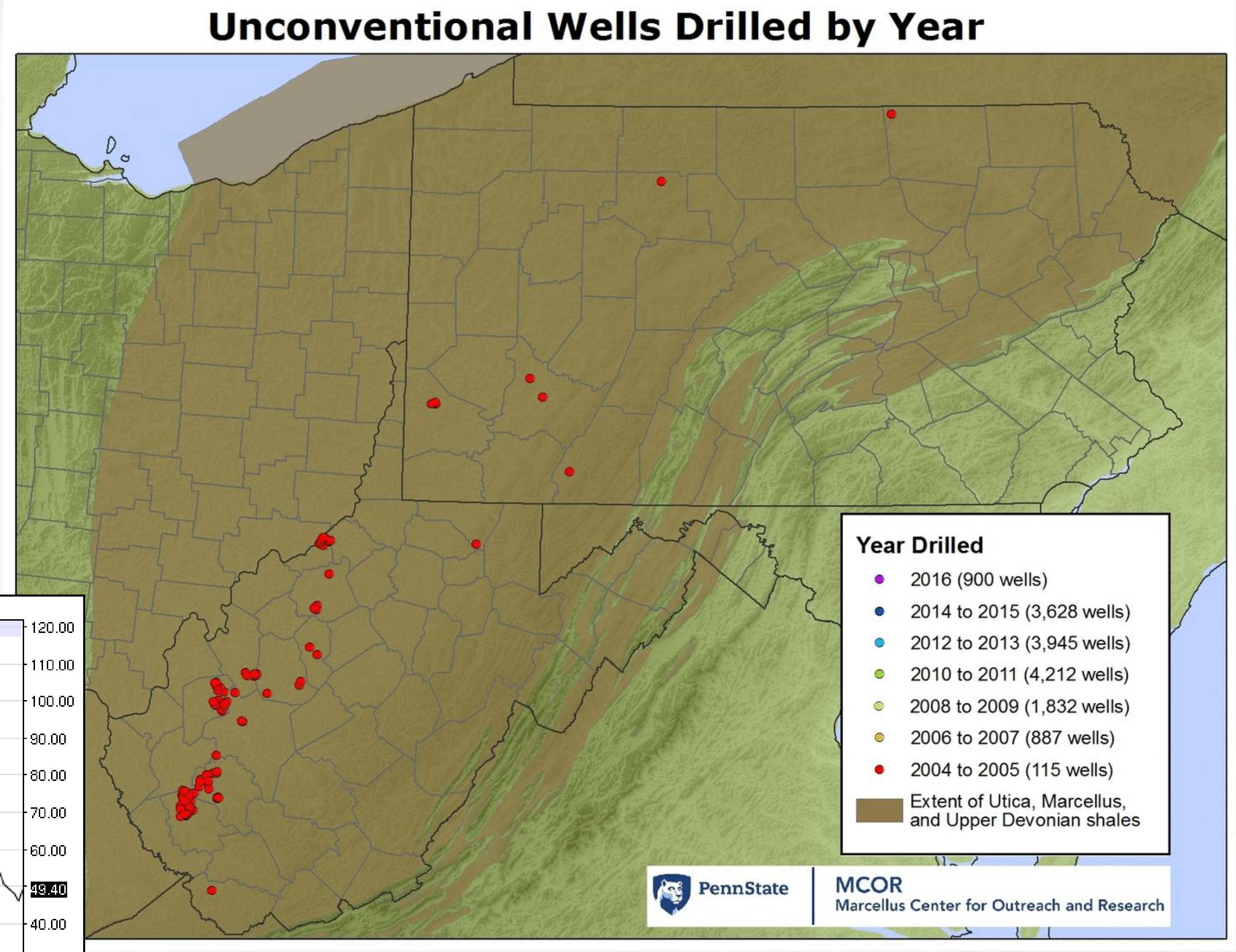
Outline

1. Project Background
   A. Shale Gas Exploration in Pennsylvania
   B. Facilities and Structures Involved in Extraction of Shale Gas
   C. Shale Formations in Pennsylvania (Marcellus, Utica, Burket/Geneseo)
   D. Oil & Gas Documents (Oil & Gas Leases, Declaration of Unitization)
   E. What is a Stacked Shale Play?
   F. Why is Forest Fragmentation an Issue?
2. Project Framework
   A. Objectives & Key Research Questions
   B. Methodology
      i. Data Management
      ii. Process 1: Forest Fragmentation Analysis
      iii. Process 2: Well Production Data Analysis
      iv. Process 3: Develop Tool based on Findings
   C. Study Area
   D. Data Sources
   E. Sharing Developed Tools and Datasets
   F. Outcomes
   G. Challenges
   H. References

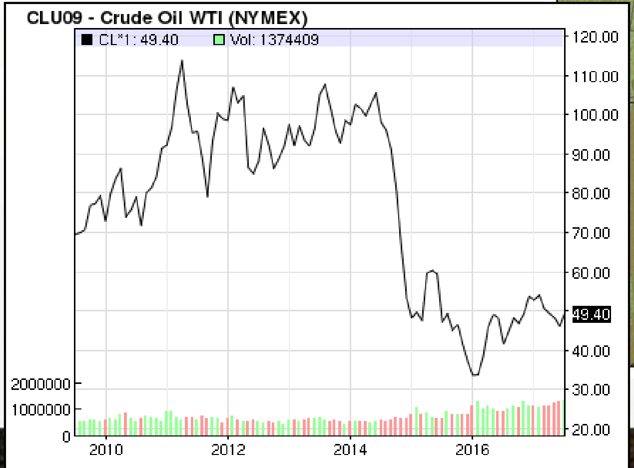
Source: Edward Todd

Shale Gas Exploration in Pennsylvania

- The Marcellus shale play began in 2003, when Range Resources drilled through the Marcellus to the Lower Silurian in Washington County, PA.
- In 2005, Range Resources drilled additional wells and experimented with hydraulic fracturing techniques, first used in the Barnett Shale in Texas.
- By 2007, the company began to successfully produce Marcellus Shale gas.
- From 2008 to 2014, gas exploration companies leased properties and drilled wells in the Marcellus Shale basin at a hurried pace.
- The price of oil and natural gas fell dramatically in mid-2014. The pace of permitted wells slowed.
- **Exploration companies need to remain focused on returns on investment, rather than production growth, as the most significant metric for success in the industry.**



Source: Penn State Center for Outreach and Research

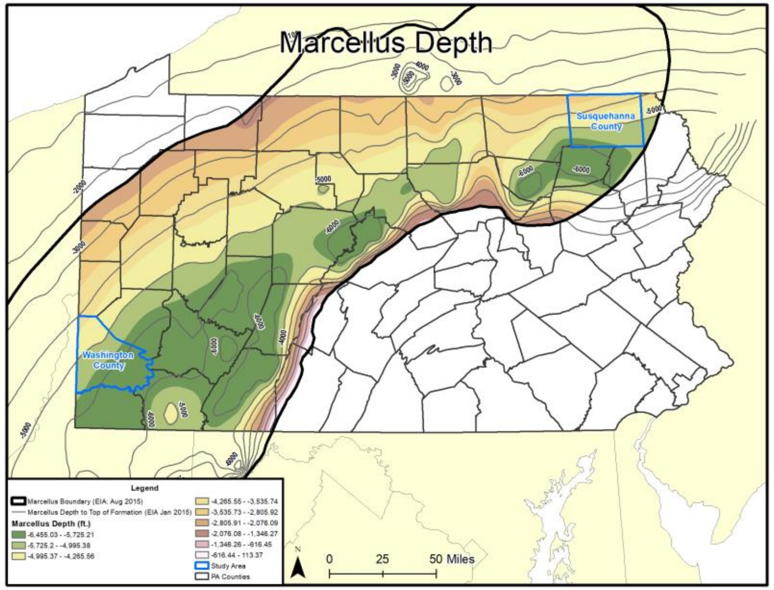


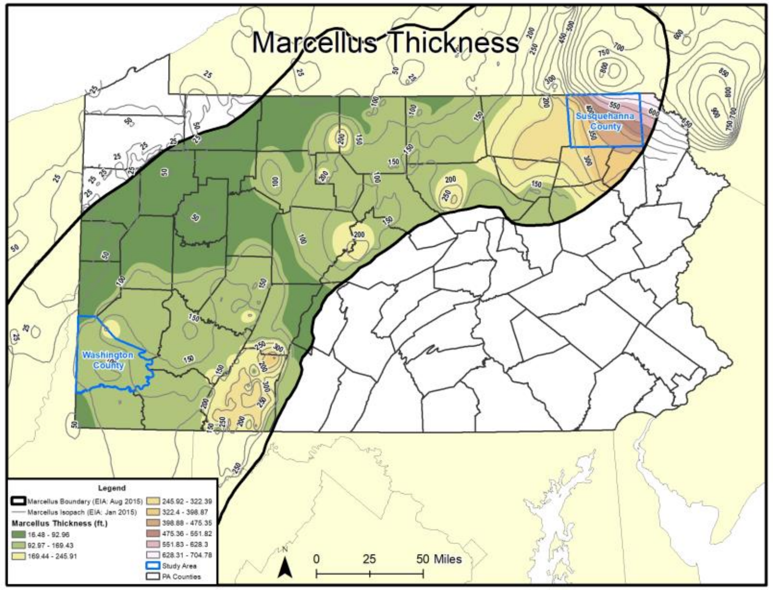
Facilities and Structures Involved in Extraction of Shale Gas

A. Well pad with horizontal drilling rig
B. Water storage tanks at a water withdrawal station
C. Water impoundment
D. Well pad with horizontal drilling rig
E. Completed well with “Christmas Tree”
F. Condensate tanks to store produced water
G. Hazard placards on the condensate tanks
H. Pipeline construction in Washington County
I. Pipeline construction liquids processing (“cryo”) plant

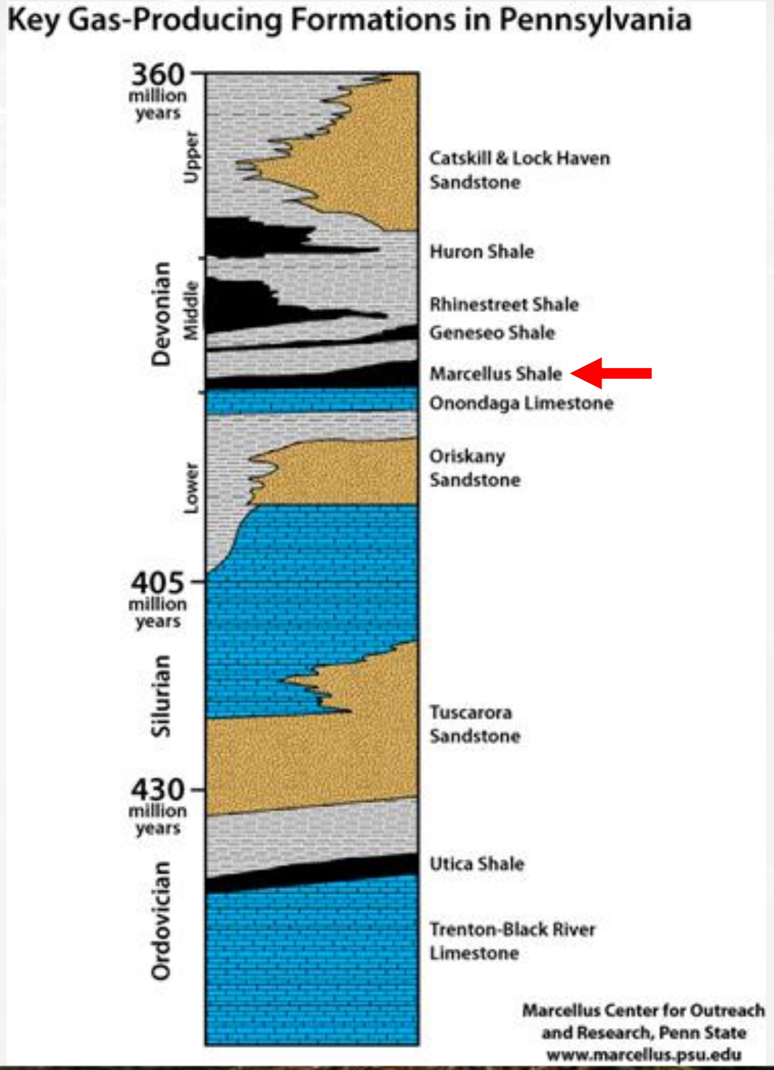
Source: (Lampe & Stolz, 2015, p.438)

Marcellus Shale in Pennsylvania

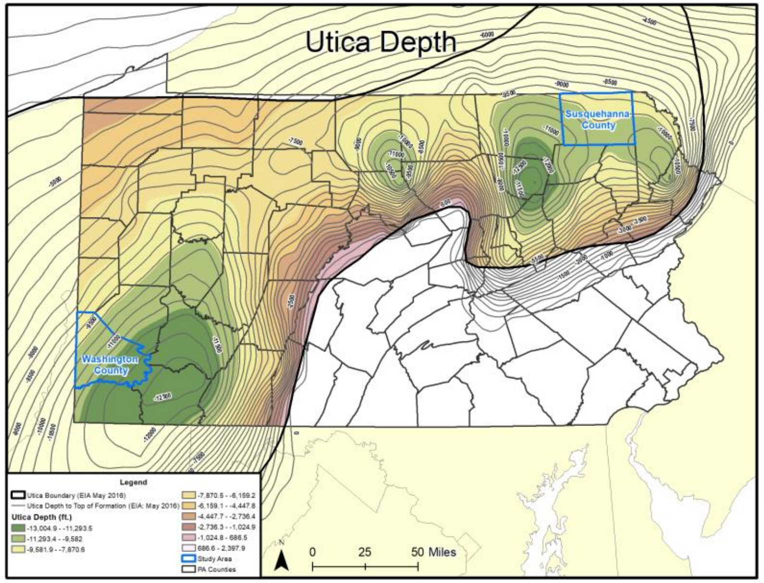


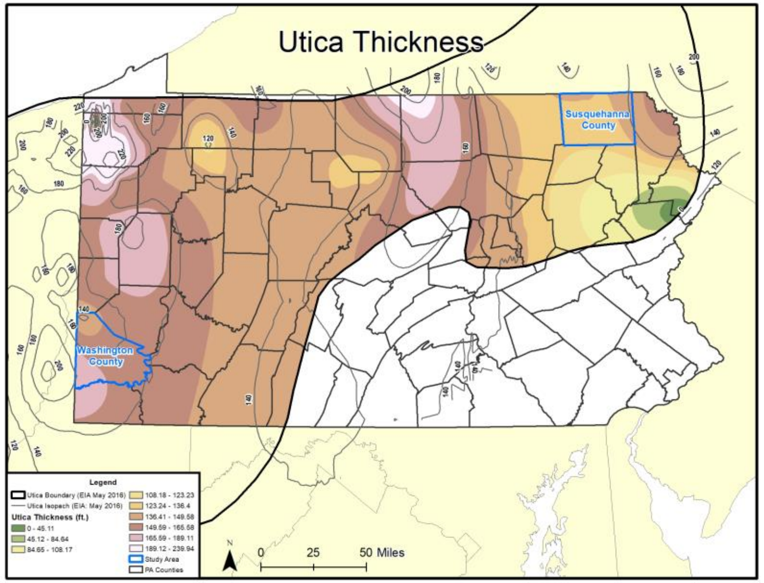


- The Marcellus Shale forms the bottom part of a thick sequence of Devonian age, sedimentary rocks in the Appalachian Basin.
- EIA (2015) estimates proven reserves in the Marcellus Play of **77.2 trillion cubic feet** (Tcf), which makes it one of the largest natural gas plays in the United States.
- Total Organic Carbon (TOC) ranges from less than **1% to 20%** (Zielinski and Mciver, 1982; Nyahay et al., 2007; Reed and Dunbar, 2008).

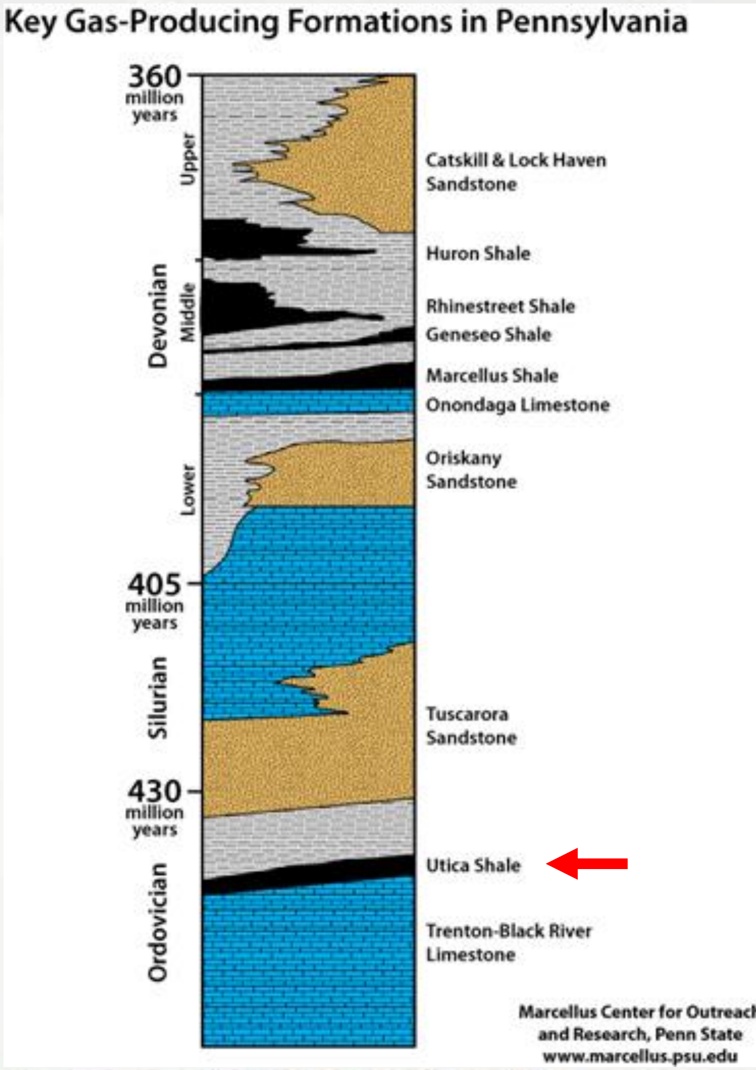


Utica Shale in Pennsylvania

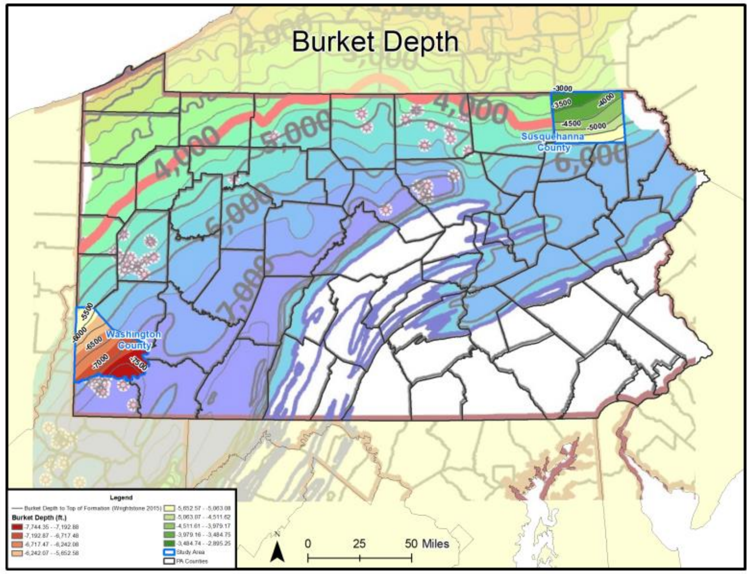


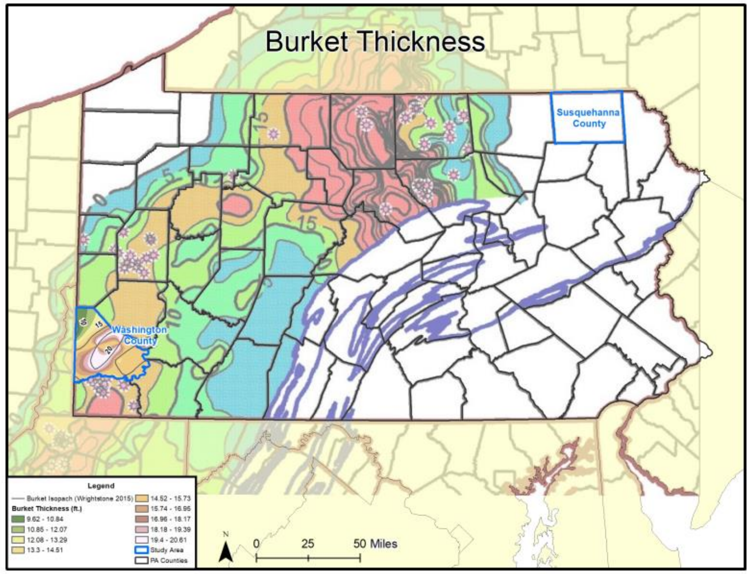


- The Utica Shale is a black, organic-rich shale of the Middle Ordovician age.
- In 2015, the WVU's Appalachian Oil and Natural Gas Research Consortium said the Utica Shale contains technically recoverable resources of an astounding **782 Tcf** of natural gas.
- Most of well drilled into the Utica Shale are in eastern Ohio.
- Total organic content (TOC) from **1% to 3%** (U.S. Energy Information Administration, 2017).

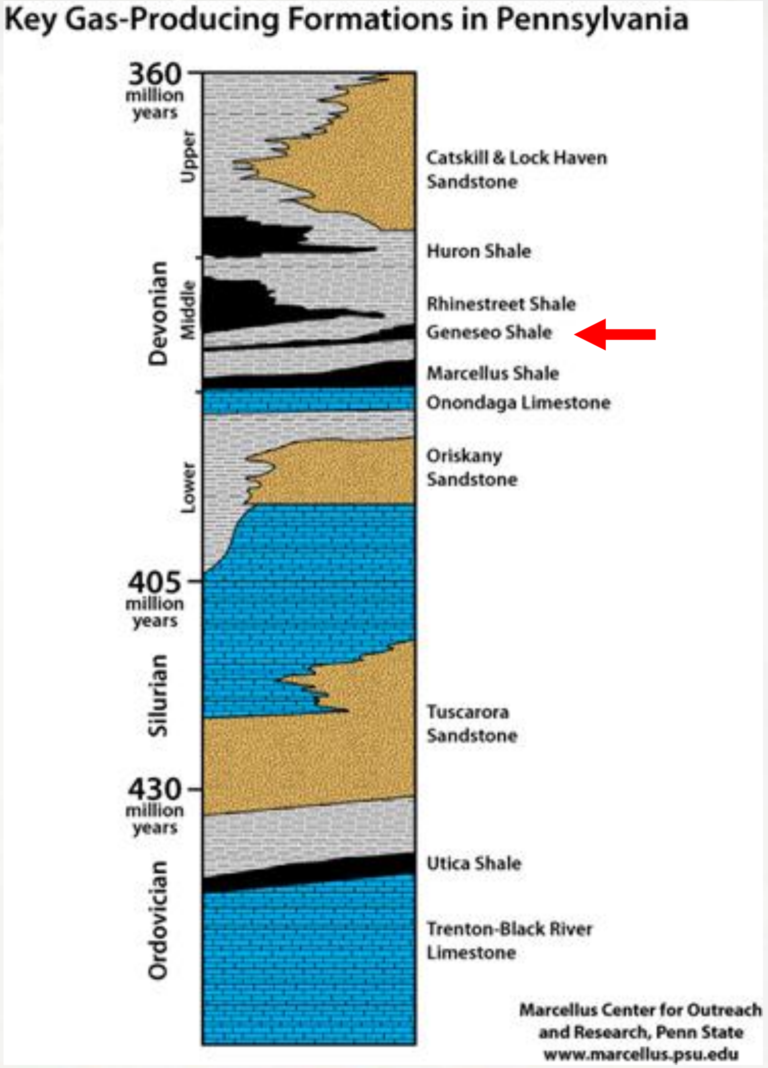


Burket/Geneseo Shale in Pennsylvania



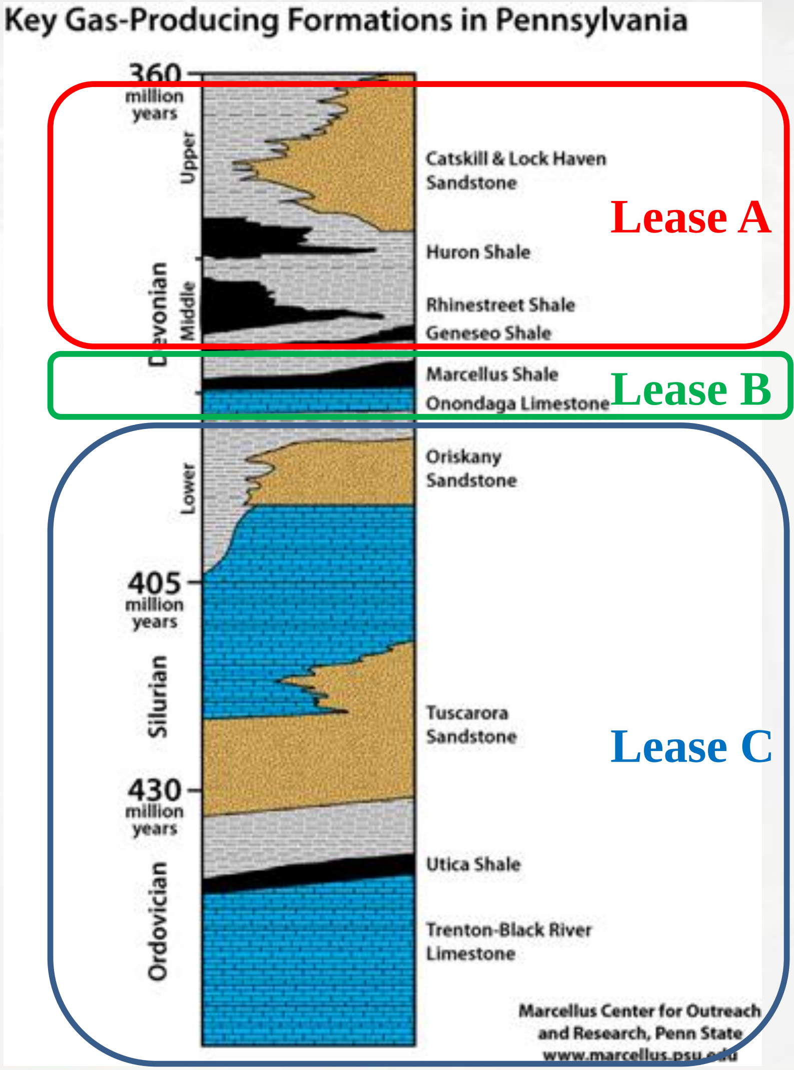


- The organic-rich mudstone immediately above Tully Limestone.
- The distance from the Burket down to the Marcellus ranges from 20 ft. in southwestern PA and WV to more than 800 ft. in northeastern PA.
- It is estimated that **33 TCF** of recoverable gas reserves in the Burket.
- Max Total Organic Content (TOC) of **3.8%** (Arnold, 2015).
- There were 85 productive wells drilled by April 2015 in the Burket (Wrightstone, 2015).



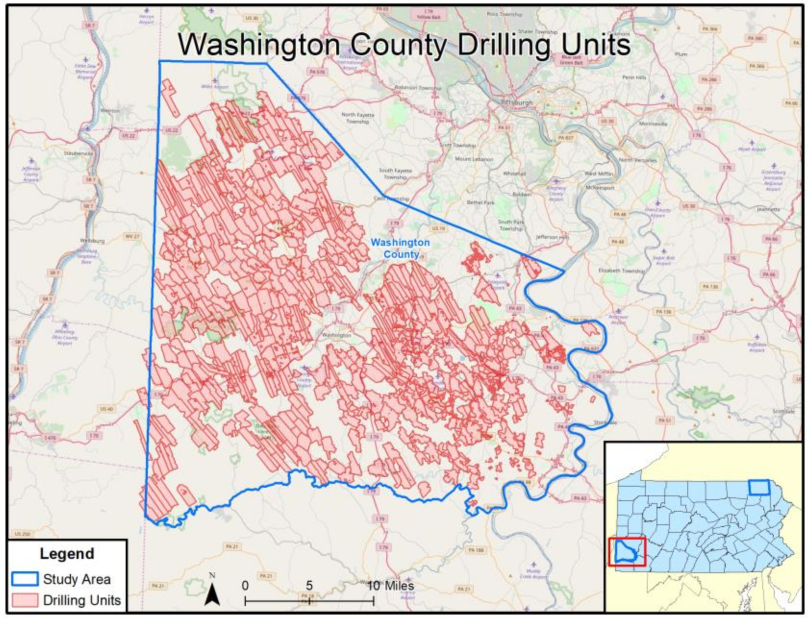
Oil & Gas Document - Oil & Gas Leases

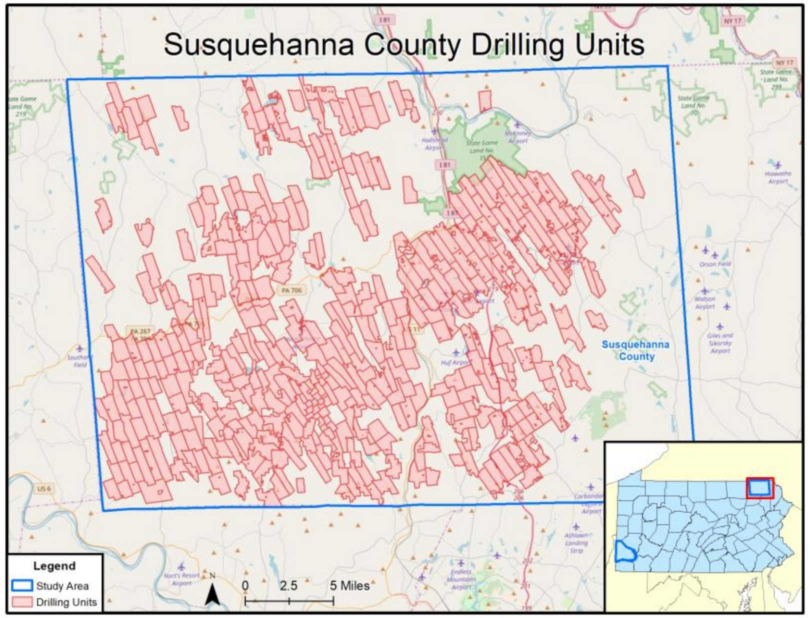
- Landman contacts a mineral owner, if no prior lease is signed, the owner can sign with the company (there is oftentimes a monetary per acre bonus when a lease is signed).
- Leases often last 5 years and have a gas royalty 12.5% to 22%.
- Frequently, the owner of the minerals is different than the owner of the surface. There may also be multiple owners of the minerals.
- Some Leases will only include mineral rights at certain depths or formations.
- Mineral owners may only own rights at certain depths or formations.

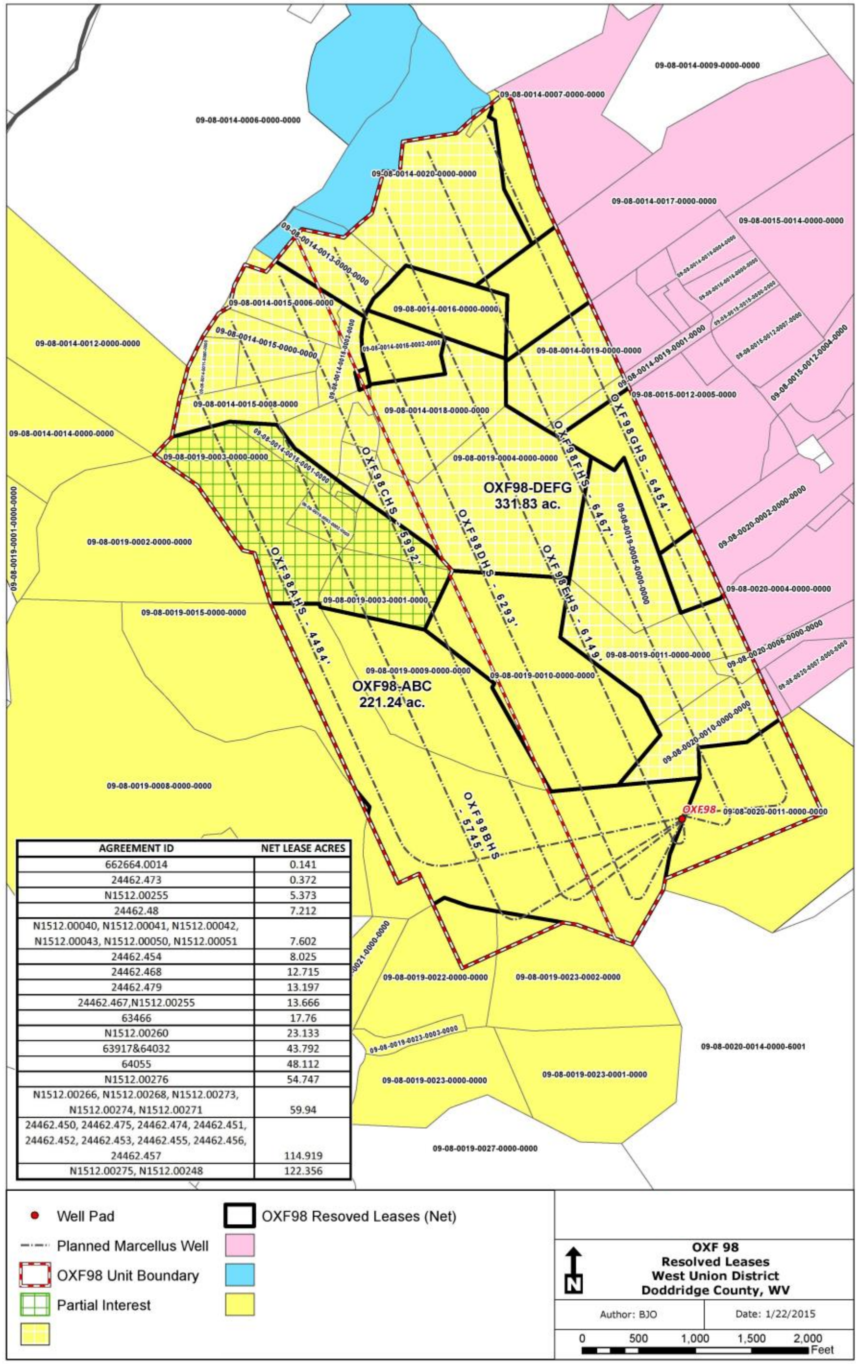


Oil & Gas Document - Declaration of Unitization

- The terms “pooling” and “unitization” are often used interchangeably.
- A pooled unit is the joining together of small tracts for the purpose of having sufficient acreage to receive a well drilling permit. Royalties of well production is shared by mineral owners in a pooled unit.
- In most cases, a Declaration of Unitization (or Pooling) is required and recorded in the county courthouse.



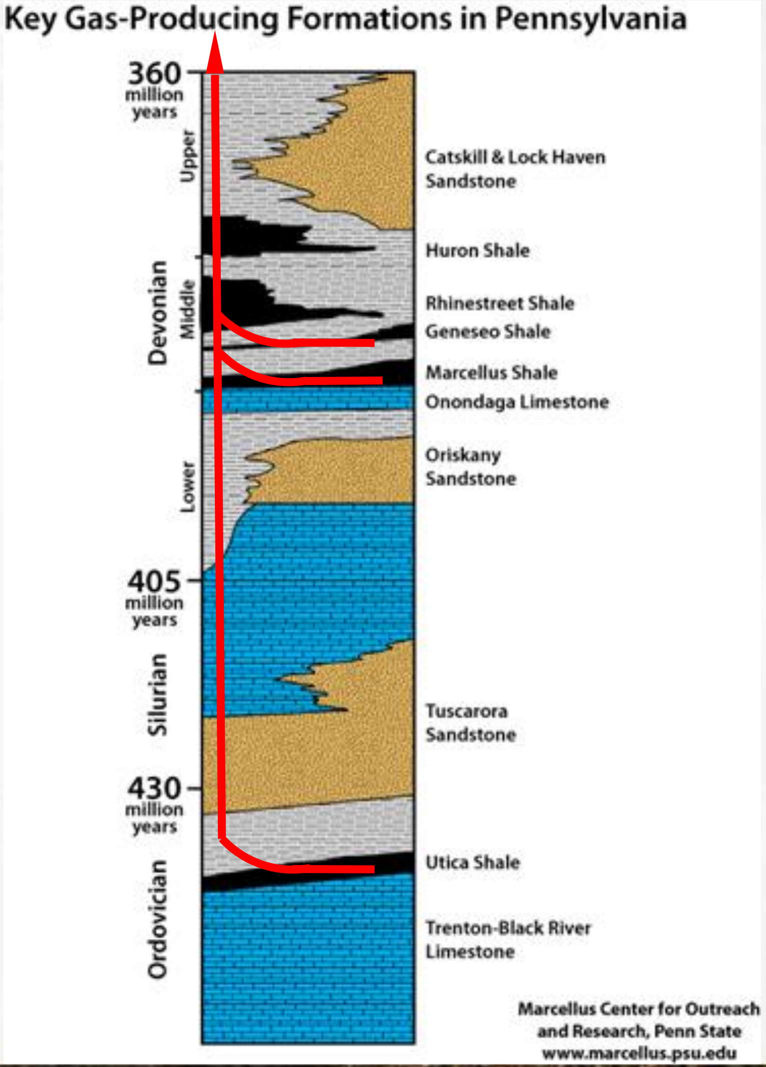




AGREEMENT ID	NET LEASE ACRES
662664.0014	0.141
24462.473	0.372
N1512.00255	5.373
24462.48	7.212
N1512.00040, N1512.00041, N1512.00042, N1512.00043, N1512.00050, N1512.00051	7.602
24462.454	8.025
24462.468	12.715
24462.479	13.197
24462.467,N1512.00255	13.666
63466	17.76
N1512.00260	23.133
63917&64032	43.792
64055	48.112
N1512.00276	54.747
N1512.00266, N1512.00268, N1512.00273, N1512.00274, N1512.00271	59.94
24462.450, 24462.475, 24462.474, 24462.451, 24462.452, 24462.453, 24462.455, 24462.456, 24462.457	114.919
N1512.00275, N1512.00248	122.356

What is a Stacked Shale Play?

- Producing from multiple shale formations from the same well pad.
- **Hypothesis:** By producing from multiple shale formations, gas exploration companies can increase well pad productivity and reduce costs, while reducing surface disruptions and forest fragmentation.



Why is Forest Fragmentation an Issue?

- **Habitat Transformation** (Langlois et al., 2017)
  - Barrier effects, created by linear corridors, can restrict movement for some wildlife species, alter home ranges, and decrease gene flow and genetic diversity.
  - Linear corridors may also be used as travel corridors by some species.
- **Plant Invasions** (Barlow et al., 2017)
  - Invasive non-native plants are moving further into PA forests around gas facilities.
  - Non-native plants are becoming a dominant part of the plant community around well pads.
- **Biodiversity** (Kiviat, 2013)
  - Lichens, bryophytes, orchids, other herbs, the West Virginia white butterfly (Pieris virginiensis), amphibians, and birds are sensitive to biodiversity resulting form forest fragmentation.
  - Runoff from mowing or spraying of herbicide could affect neighboring habitats.

Objectives & Key Research Questions

- Where and to what extent is forest fragmentation occurring?
- Where are locations that a stacked well pad could be both viable and profitable in Pennsylvania?
- What impact does a stacked well pad have on reducing habitat fragmentation?
- How can GIS be better utilized to ensure a stacked well pad is viable, developed on time, and within budget?

Methodology

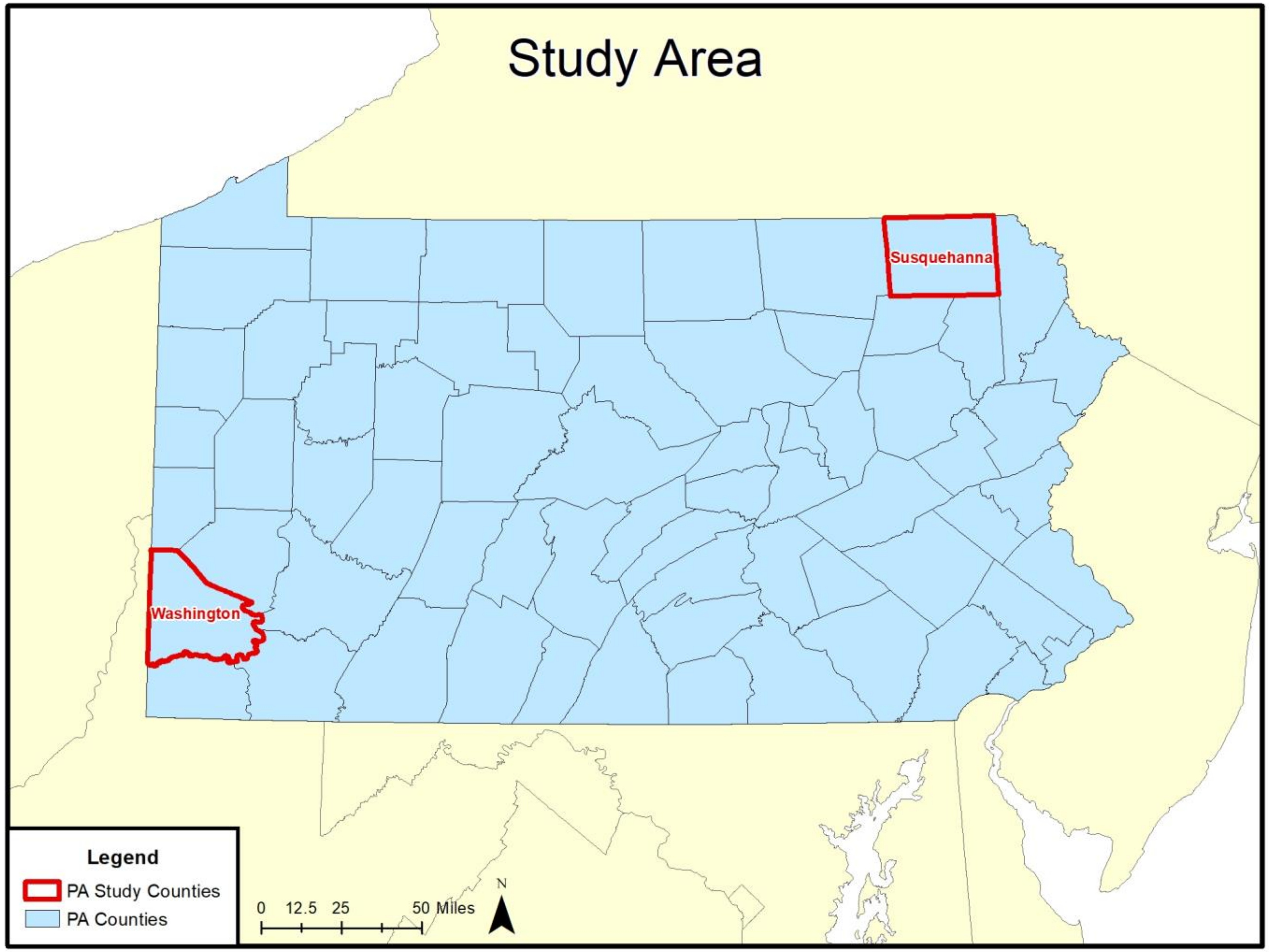
- Data Management
  - Well Production Dataset
  - Digitizing Drilling Units & Generating the Study Area for Process 1
- Process 1: Forest Fragmentation Analysis
- Process 2: Well Production Data Analysis
- Process 3: Develop Tool based on Findings

Software:

- ArcGIS Desktop 10.4 (Spatial Analyst, Geostatistical Analyst extensions)
- ArcGIS Pro 2.0.1
- Python 2.7
- R and RStudio
- GeoDa
- Balsamiq
- Esri Web AppBuilder
- ArcGIS Online
- FME

Study Area

- Process 1: Susquehanna County, PA
- Process 2 & 3: Susquehanna and Washington Counties



Data Sources

Land Cover (Pre-Exploration) - PAMAP Program Land Cover for Pennsylvania, **2005 (30 meter resolution)** Will be resampled to a 1 m x 1 m resolution.
http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1100

Land Cover (Post-Exploration) - High-Resolution Land Cover, Commonwealth of Pennsylvania, Chesapeake Bay Watershed and Delaware River Basin, **2013 (1 meter resolution)**
http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=3193

Well Data - Reported Production from the Pennsylvania DEP
http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?%2fOil_Gas%2fOil_Gas_Well_Production

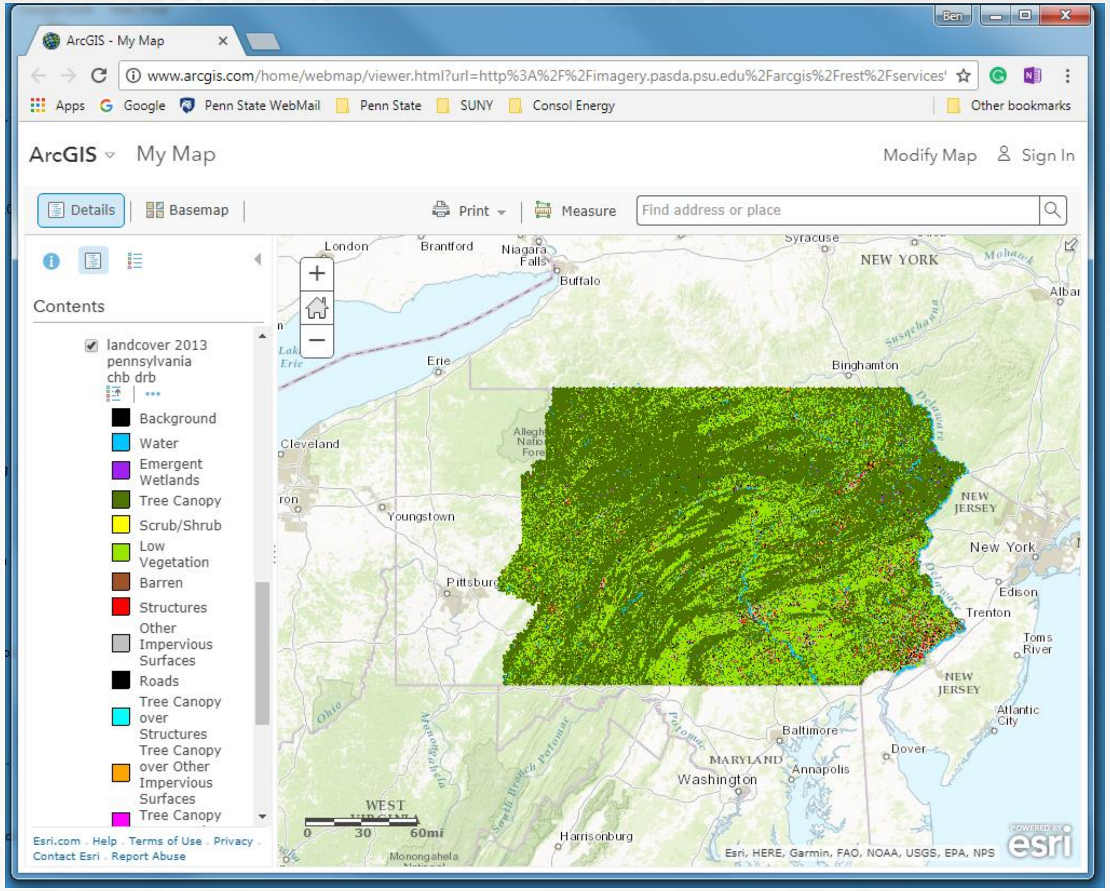
Unit Declaration Data – Digitized from data recorded in PA County Courthouses

Williams Partners L.P. existing Susquehanna County gathering lines
http://atlanticsunriseexpansion.com/wp-content/uploads/2015/06/Susquehanna-4-29-15.pdf

Digital Elevation Model from the 2006 - 2008 - DCNR PAMAP Program -
http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1247

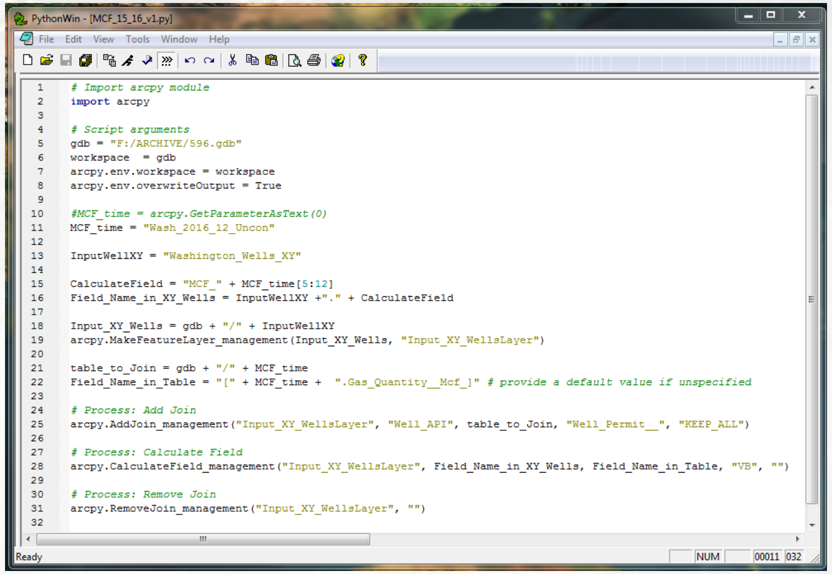
EIA shale formation isopach and elevation data
https://www.eia.gov/maps/layer_info-m.php

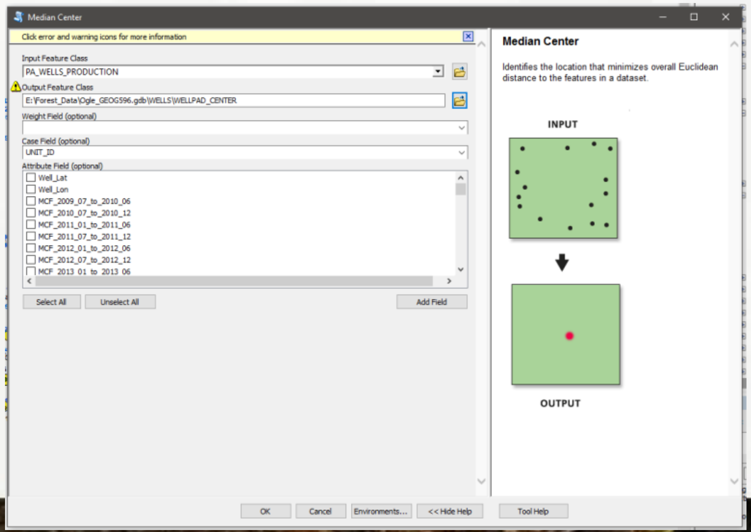
EIA Natural Gas Interstate and Intrastate Pipelines
https://www.eia.gov/maps/layer_info-m.php



Data Management - Well Production Dataset

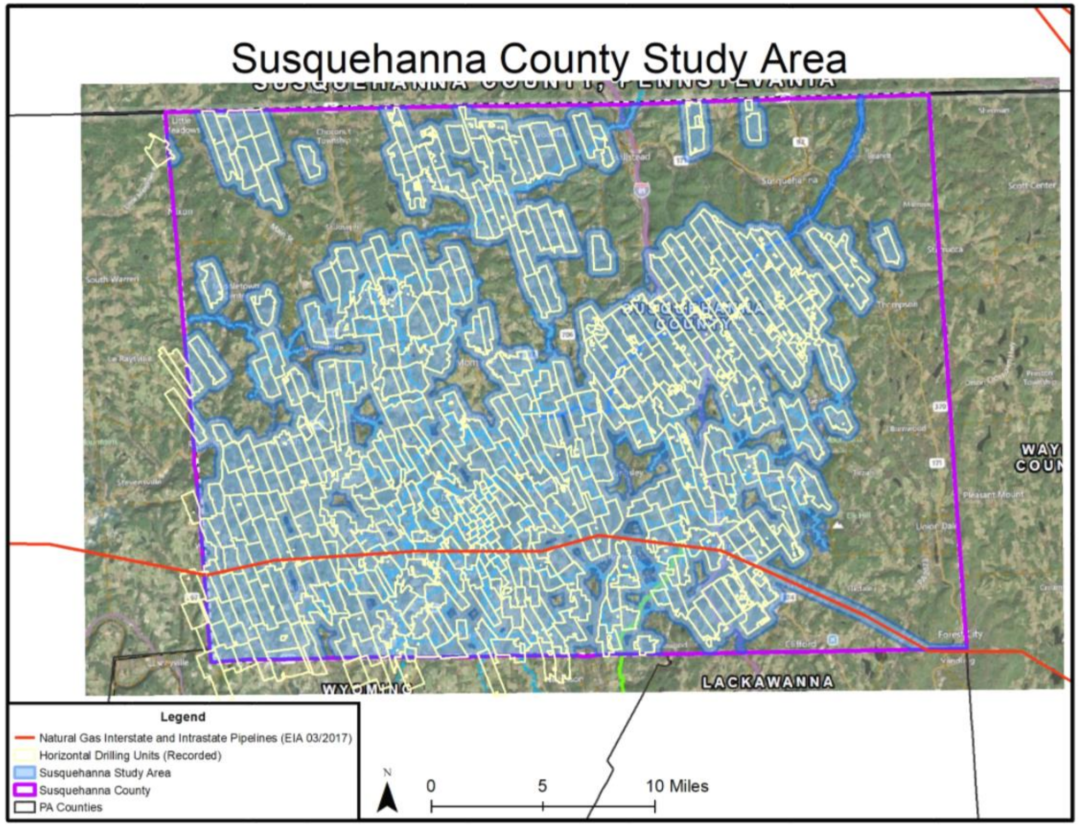
- Exported unconventional well production data (.xls) from 2005 through 2013 from PA DEP website.
- Generate a feature class using FME Desktop (convert .xls to FileGDB).
- Python script automated the process of joining of the well tables (32) and calculated the monthly (or semi-annual) production data to the well feature class by well api.
- HIGHEST_MCF_PRODUCTION field was created and attributed using an update cursor.
- Wellpad Centers were created using Median Center geoprocessing tool.

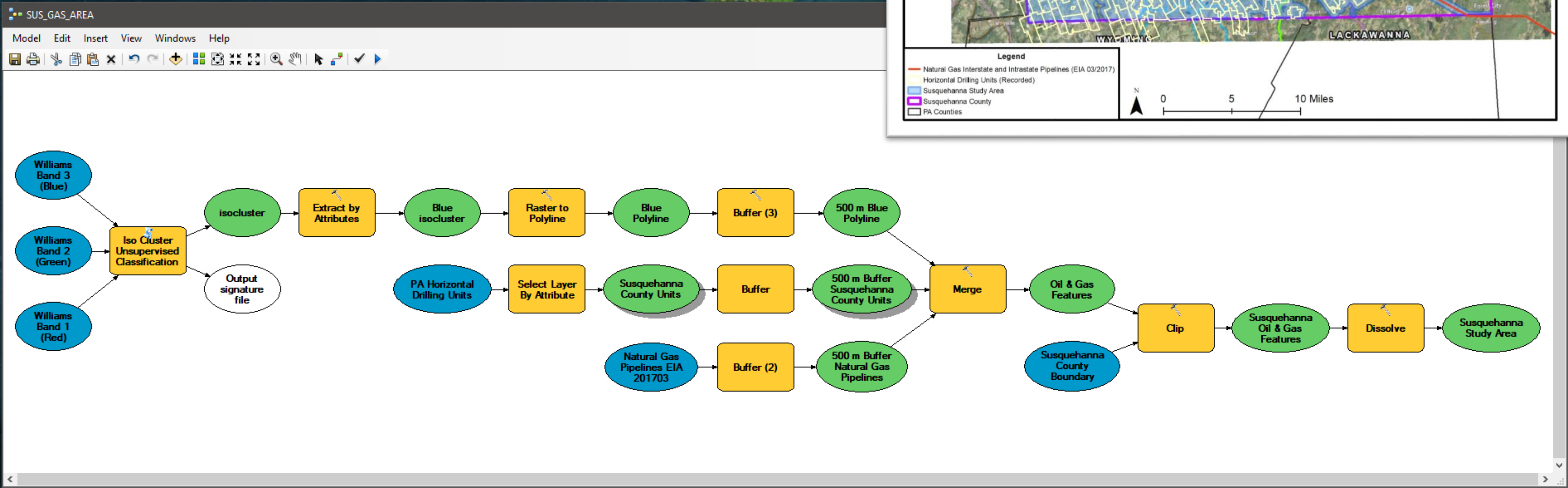




Data Management - Digitizing Drilling Units & Generating the Study Area for Process 1

- Drilling units digitized from Declaration of Unitization documents recorded in the county courthouse.
- Created a study area by buffering (500 m) around recorded drilling units of producing well pad locations, pipeline datasets using Esri ModelBuilder.



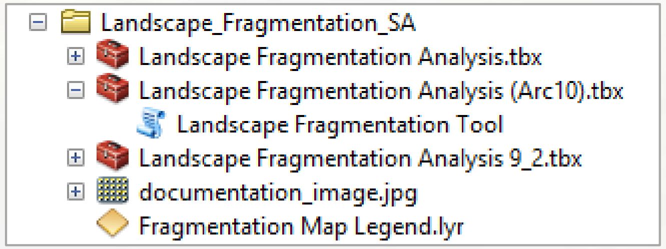


Process 1: Forest Fragmentation Analysis

- Create a tool using Python that will:
  1. Reclassify the 2005 and 2013 land cover datasets (0 = not analyzed, 1 = non-forest, 2 = forest).
  2. Use the Landscape Fragmentation Tool (LFT) v 2.0 to categorize the forested areas into four main categories - patch, edge, perforated, and core.
  3. Calculate the acreages and percentages of each fragmentation category.
- Analyze the results using GeoDa.

Landscape Fragmentation Tool (LFT) v 2.0

- Developed by Vogt et al. (2007), this tool classifies a land cover type of interest into four main categories - patch, edge, perforated, and core.
- The edge width for this analysis was 100 meters.
- The core category is further divided based on the area of the core tract.
  - Small core patches are less than 250 acres
  - Medium core patches are between 250 and 500 acres
  - Large core patches are greater than 500 acres



Core (interior)

Perforated

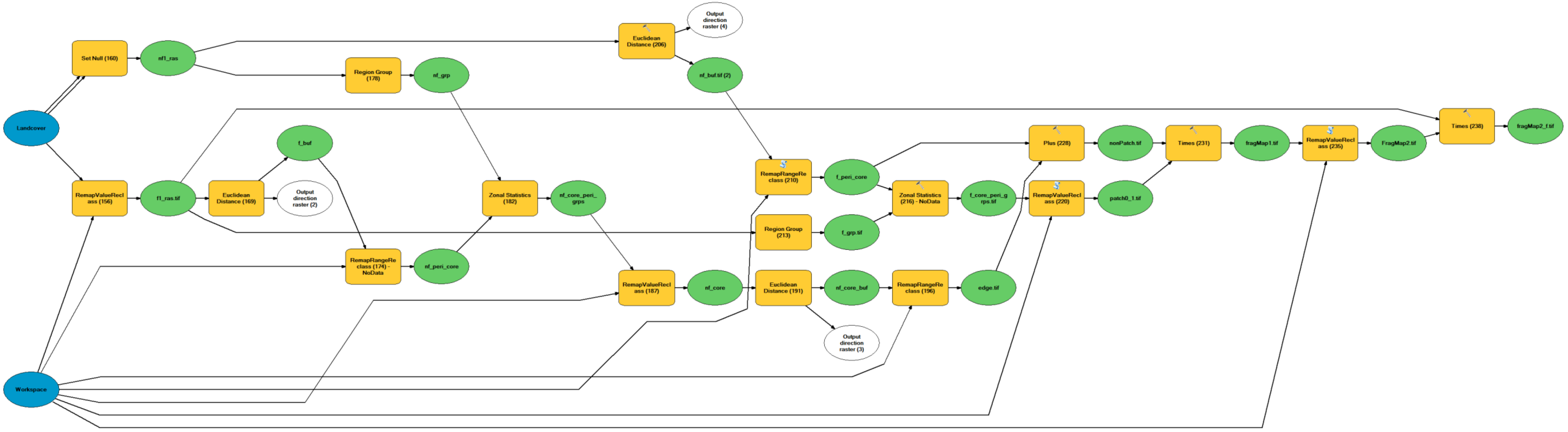
Edge

Patch

Source: (Vogt et al., 2007)

Landscape Fragmentation Tool (LFT) v 2.0

- Reclassification, Euclidian Distance, Set Null, Zonal Statistics, Region Group, Plus, and Times geoprocessing tools were all used in this workflow.
- ArcGIS Pro 64-bit geoprocessing helped speed up the model.



Forest Fragmentation Webmap

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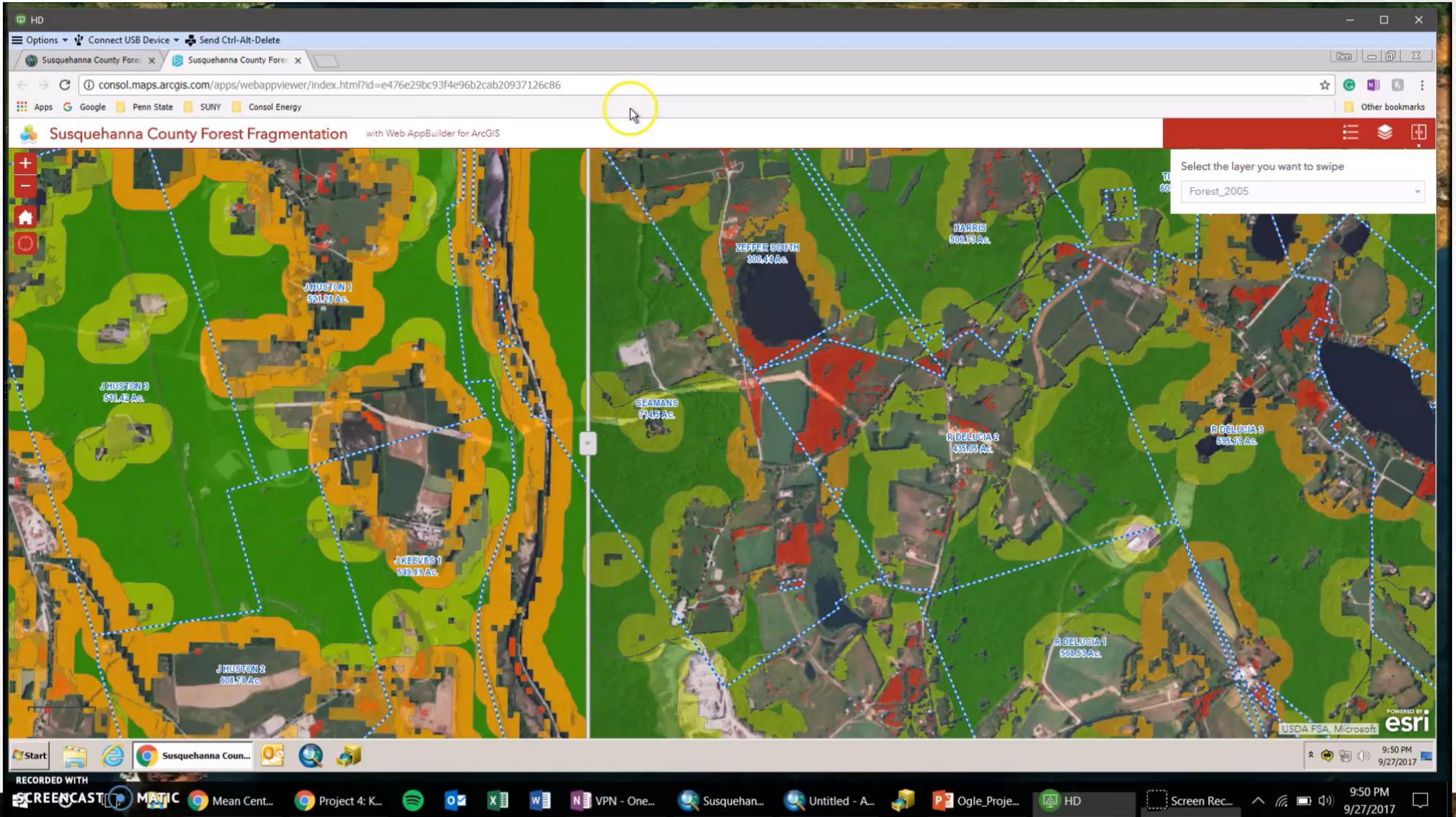
Efficiency Made Possible through Online Web Maps & Enterprise Reporting

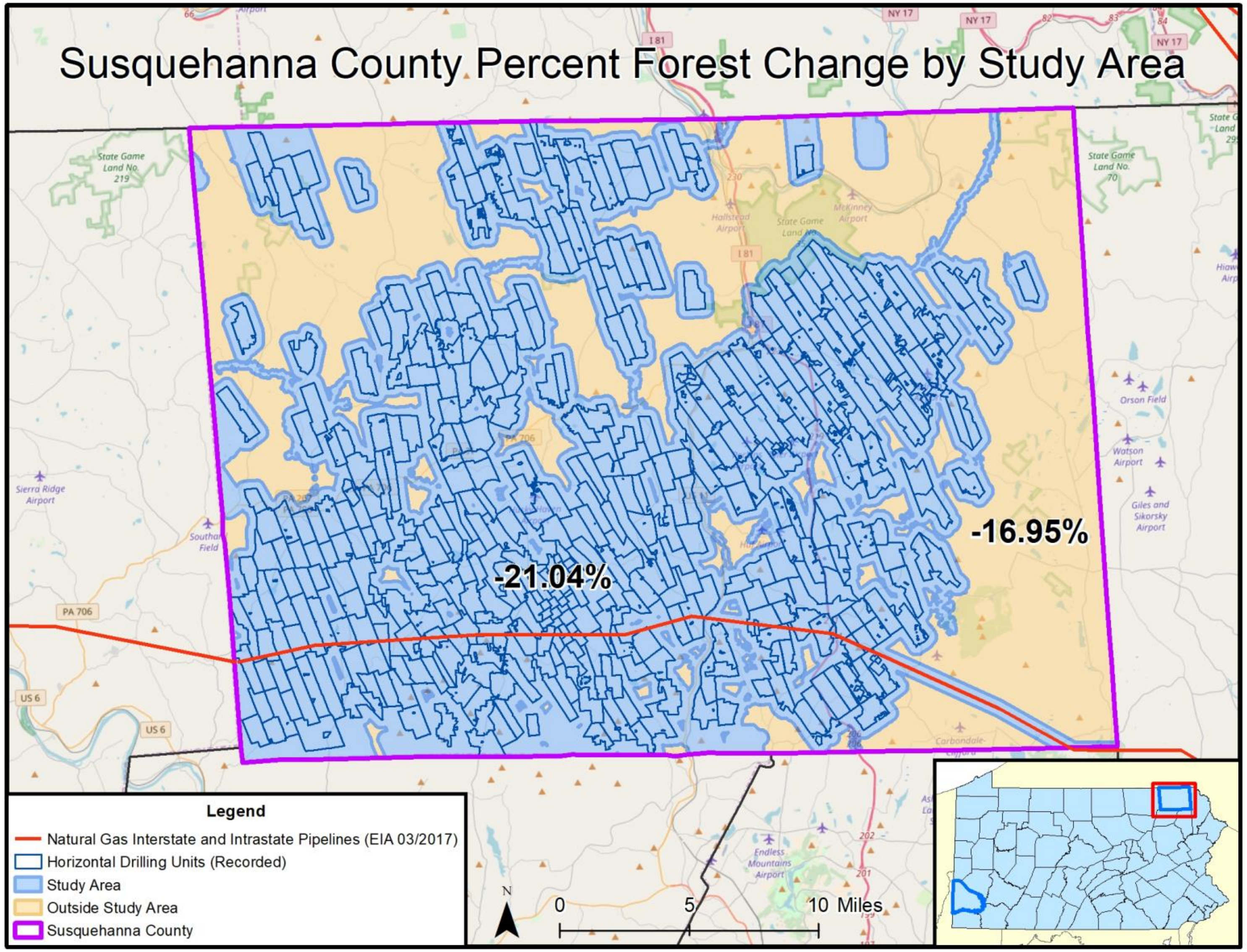


Susquehanna Drilling Units

2005 Forest Fragmentation Classes

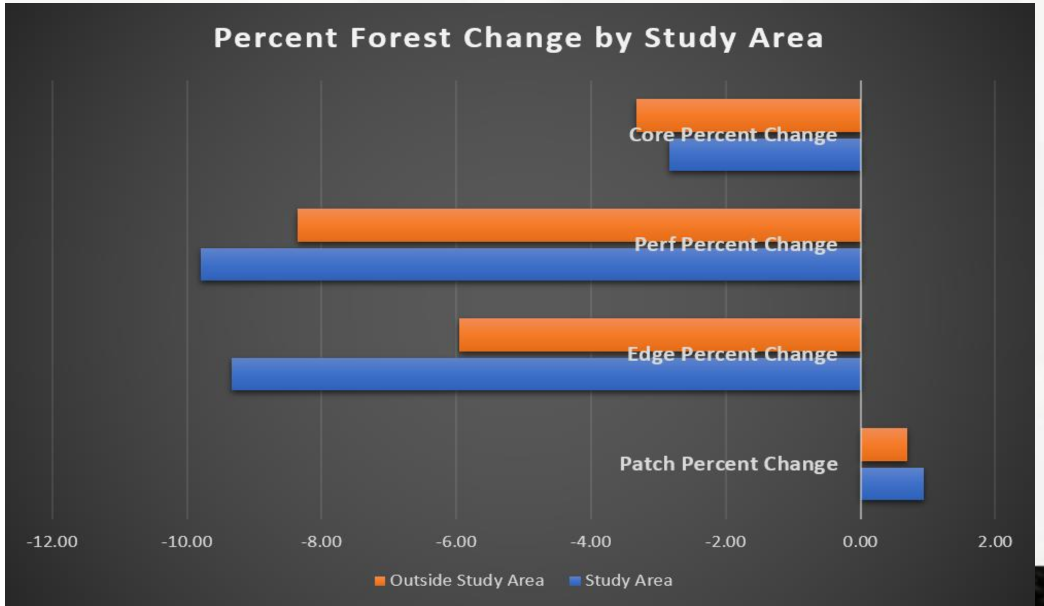
- Patch
- Edge
- Perforated
- Core

Percent Forest Change by Study Area

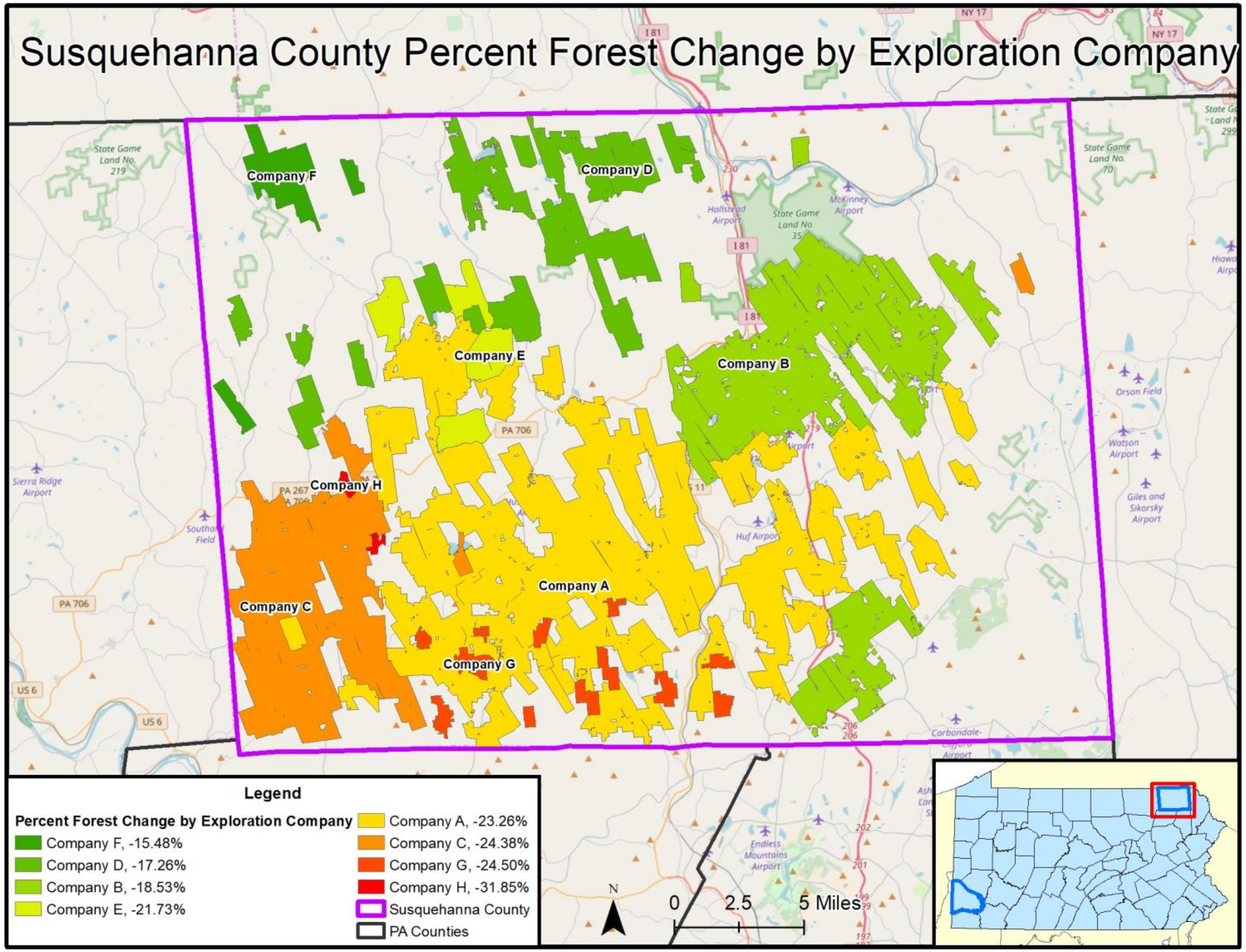


Study Location	Count Medium Core Change	Percent Medium Core Change	Count Large Core Change	Percent Large Core Change
Study Area	-42	3.79	5	-15.83
Outside Study Area	-24	4.79	-20	-16.05

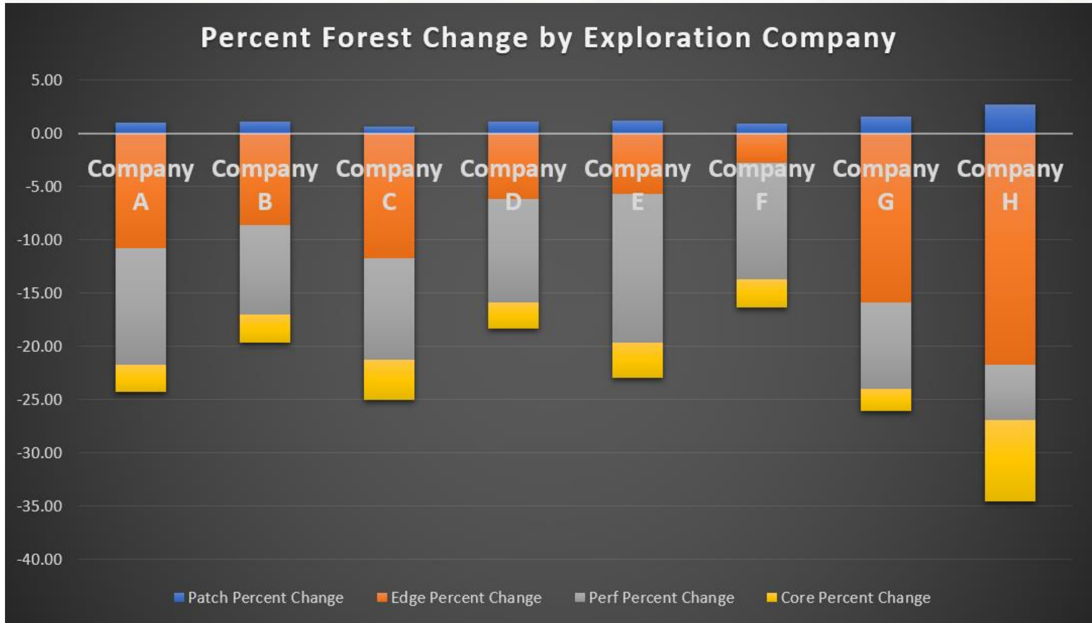
Study Location	Study Area	Patch Percent Change	Edge Percent Change	Perf Percent Change	Core Percent Change	Percent Forest Change
Study Area	341617.01	0.93	-9.34	-9.79	-2.84	-21.04
Outside Study Area	190915.50	0.70	-5.96	-8.36	-3.32	-16.95
AVG:		0.81	-7.65	-9.08	-3.08	-18.99
STDEV:		0.12	1.69	0.71	0.24	2.04



Percent Forest Change by Exploration Company

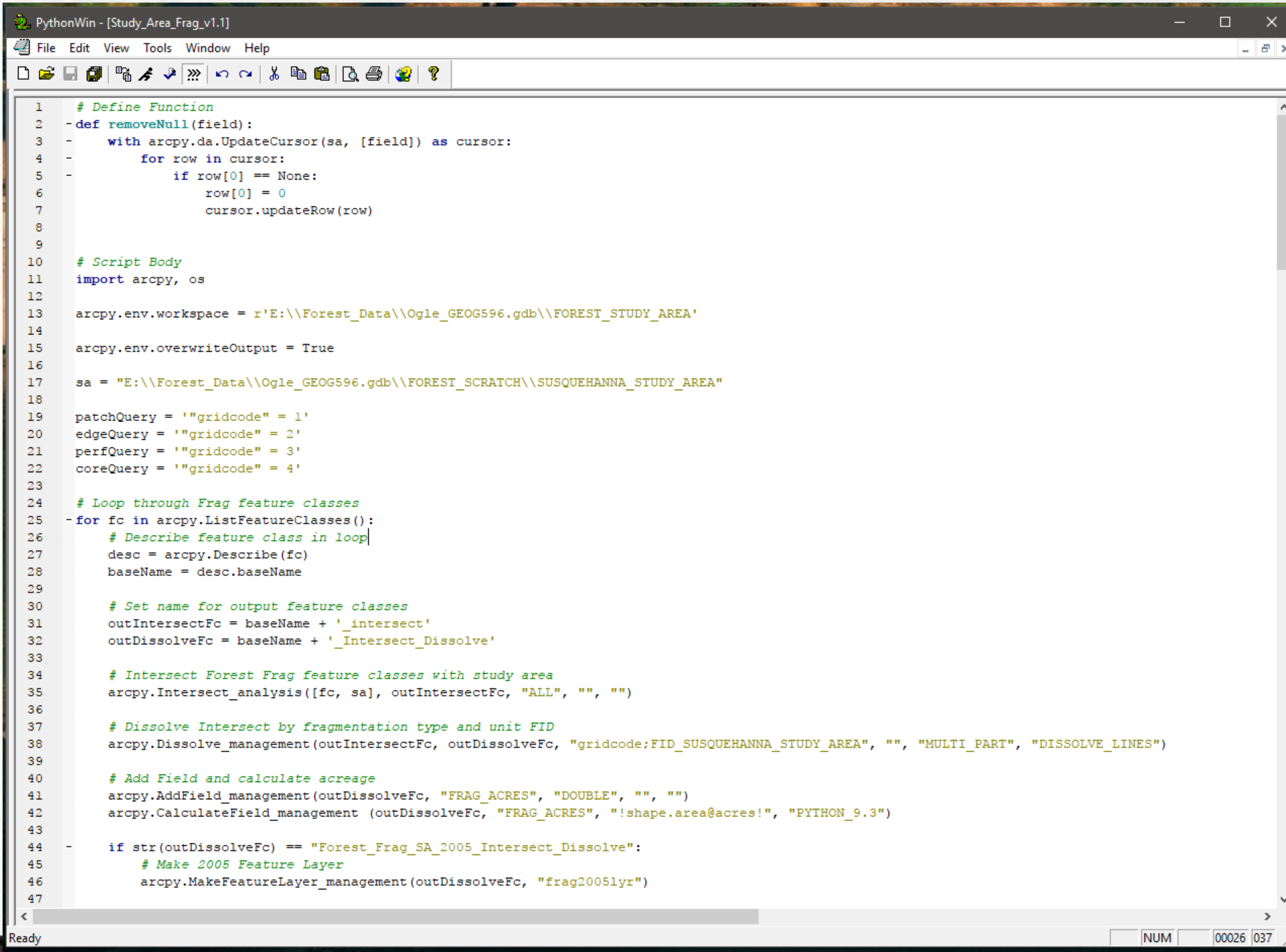


Company	Total Unit Acres	Patch Percent Change	Edge Percent Change	Perf Percent Change	Core Percent Change	Percent Forest Change
Company A	93721.10	0.97	-10.77	-10.94	-2.52	-23.26
Company B	44317.36	1.08	-8.59	-8.42	-2.60	-18.53
Company C	30931.37	0.67	-11.74	-9.54	-3.76	-24.37
Company D	24263.48	1.05	-6.17	-9.75	-2.39	-17.26
Company E	6466.39	1.23	-5.69	-13.94	-3.33	-21.73
Company F	4804.12	0.88	-2.76	-10.96	-2.64	-15.48
Company G	4540.44	1.56	-15.88	-8.08	-2.11	-24.50
Company H	438.74	2.68	-21.73	-5.16	-7.63	-31.85
AVG:	26185.38	1.26	-10.42	-9.60	-3.37	-22.12
STDEV:	29354.41	0.59	5.72	2.39	1.69	4.84



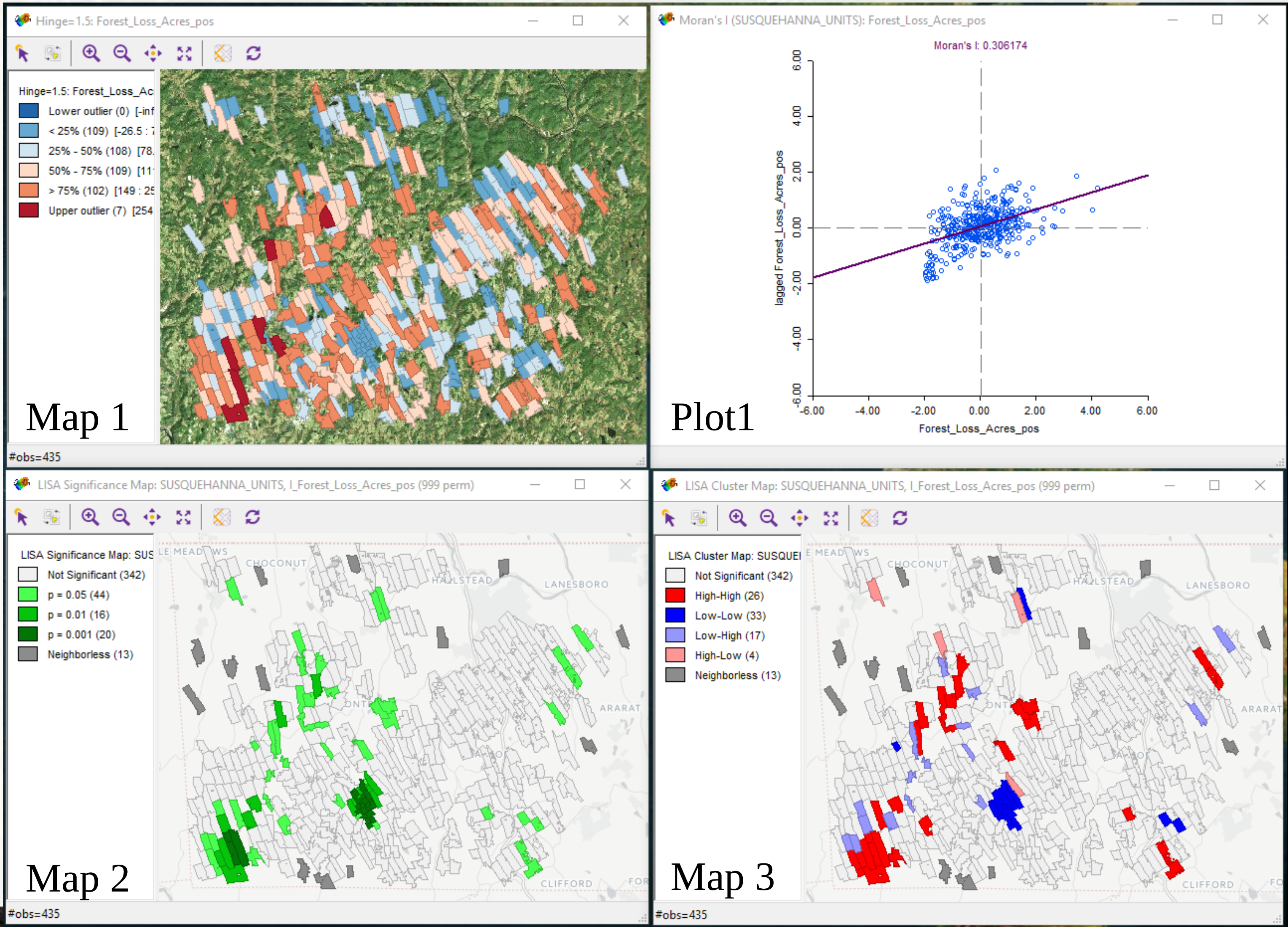
Local Indicators of Spatial Association (LISA) Analysis of Fragmentation

- Perform the same calculations of forest fragmentation by the following areas:
  - Unit
  - Municipality
  - 1 km x 1 km grid
- Python Script:
  - Intersect (area, fragmentation fc)
  - Dissolve (by fragmentation class)
  - Calculate Acreage of fragmentation classes
  - Add Join
  - Remove Null values (update cursor)
  - Calculate percent and acreage change by fragmentation class
- Analyze Local Indicators of Spatial Association (LISA) using GeoDa.



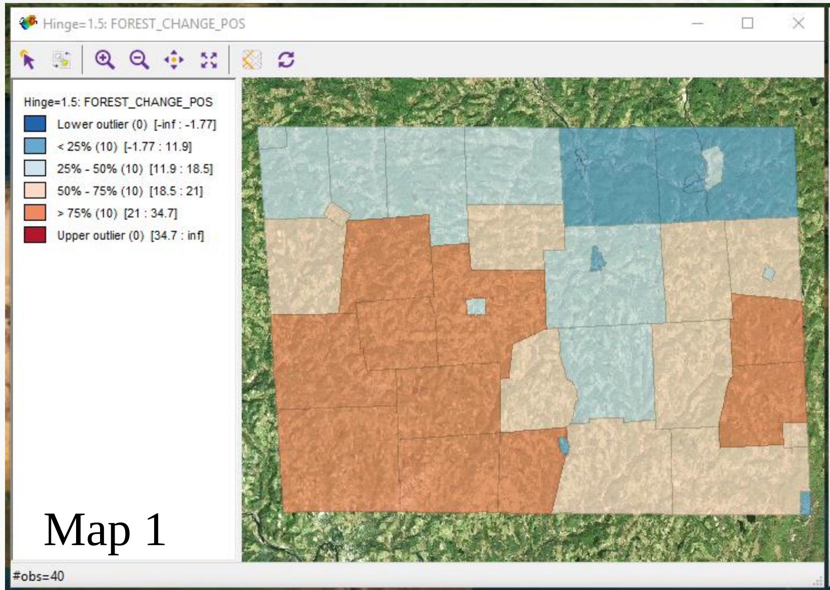
LISA Analysis by Drilling Unit

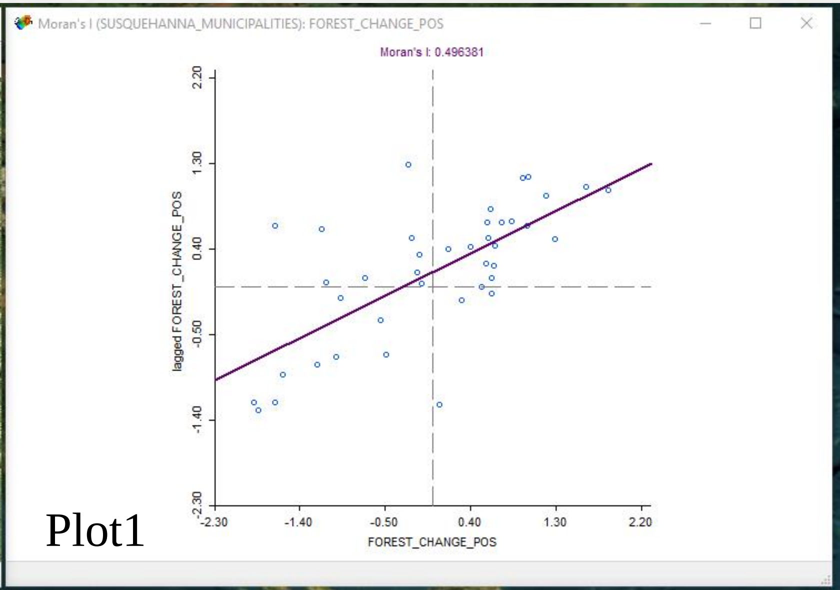
- Map 1 is a box map of **Percent Forest Loss by Drilling Unit.**
- Plot 1 is a Moran's I scatterplot
  - Moran's I = 0.306
  - Strong positive spatial autocorrelation
- Map 2 is the LISA significance map.
  - Darker shades of green contribute to the local significance, while areas in white are non-significant locations.
- Map 3 is the LISA cluster map.
  - Shows units that significantly contributed to the positive autocorrelation.
- **Dismiss spatial randomness** and can locate and characterize the clusters of units.

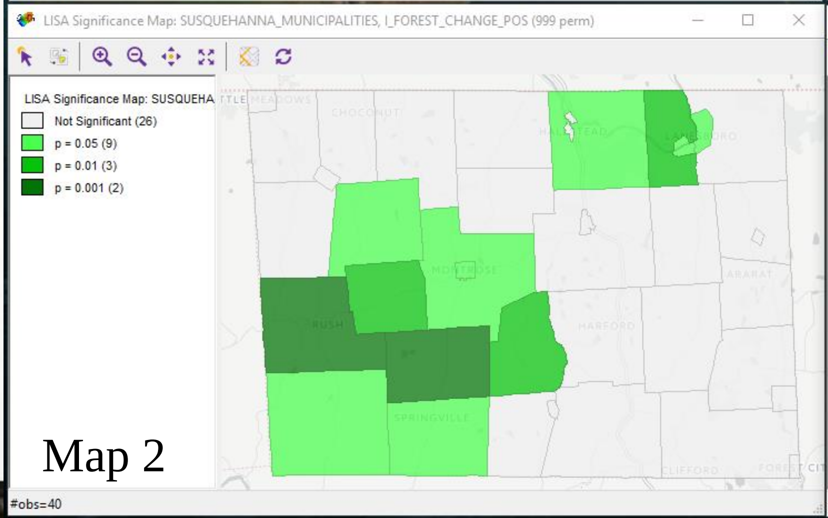


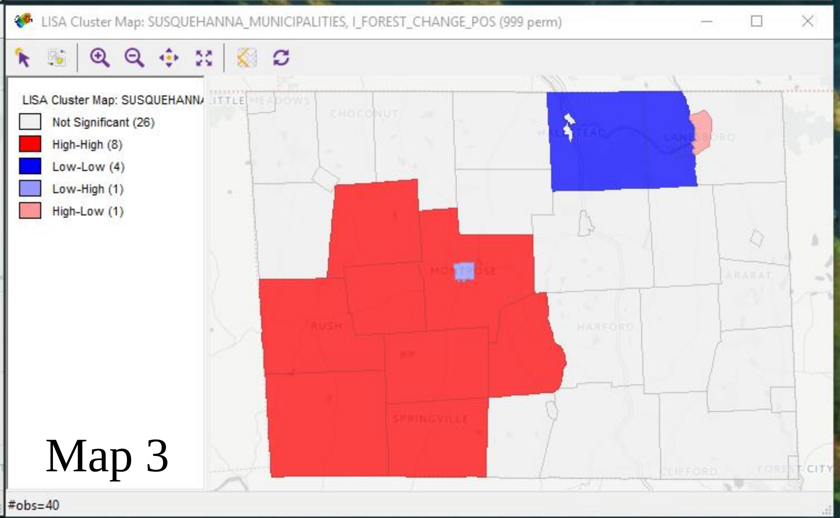
LISA Analysis by Municipality

- Map 1 is a box map of **Percent Forest Loss by Municipality.**
- Plot 1 is a Moran's I scatterplot
  - Moran's I = 0.406
  - Strong positive spatial autocorrelation
- Map 2 is the LISA significance map.
  - Darker shades of green contribute to the local significance, while areas in white are non-significant locations.
- Map 3 is the LISA cluster map.
  - Shows municipalities that significantly contributed to the positive autocorrelation.
- **Dismiss spatial randomness** and can locate and characterize the clusters of municipalities.



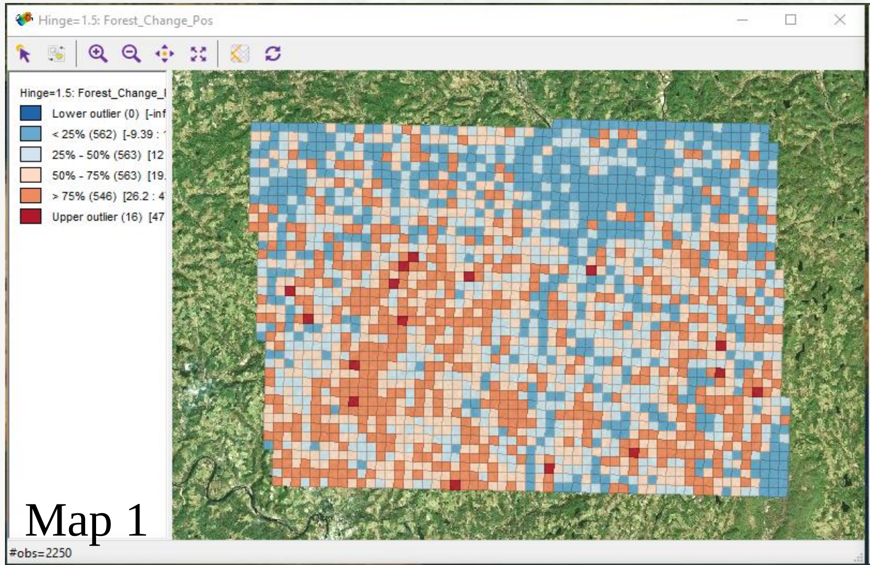




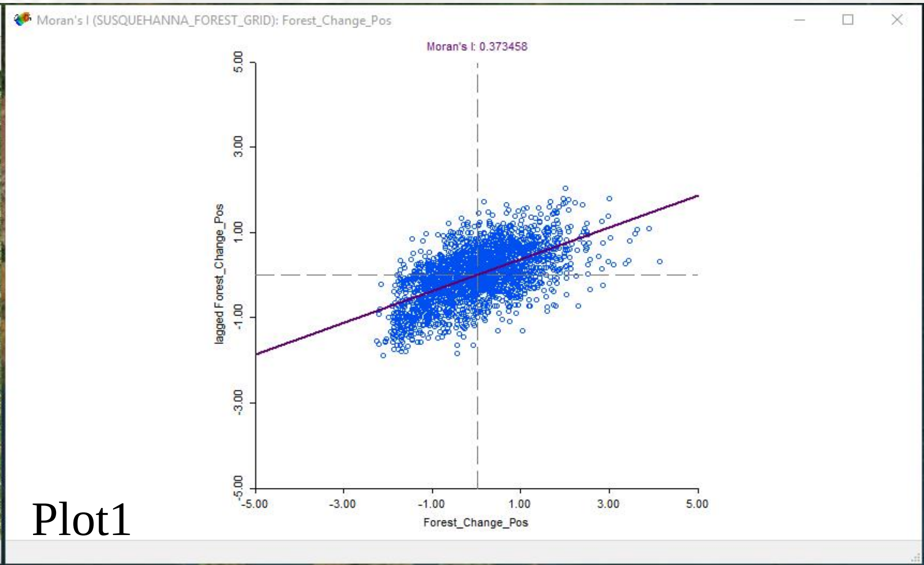


LISA Analysis by 1 km x 1 km Grid

- Map 1 is a box map of **Percent Forest Loss by Grid.**
- Plot 1 is a Moran's I scatterplot
  - Moran's I = 0.373
  - Strong positive spatial autocorrelation
- Map 2 is the LISA significance map.
  - Darker shades of green contribute to the local significance, while areas in white are non-significant locations.
- Map 3 is the LISA cluster map.
  - Shows grids that significantly contributed to the positive autocorrelation.
- **Dismiss spatial randomness** and can locate and characterize the clusters of grids.

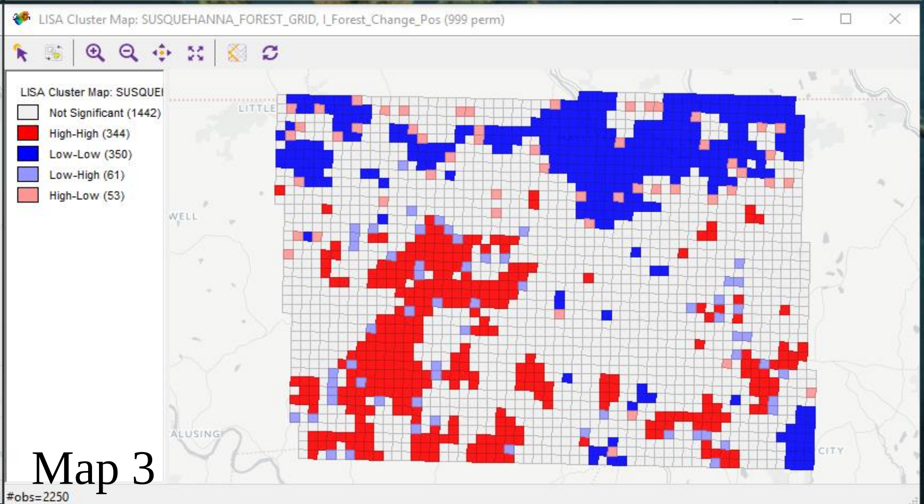


Map 1



Plot1

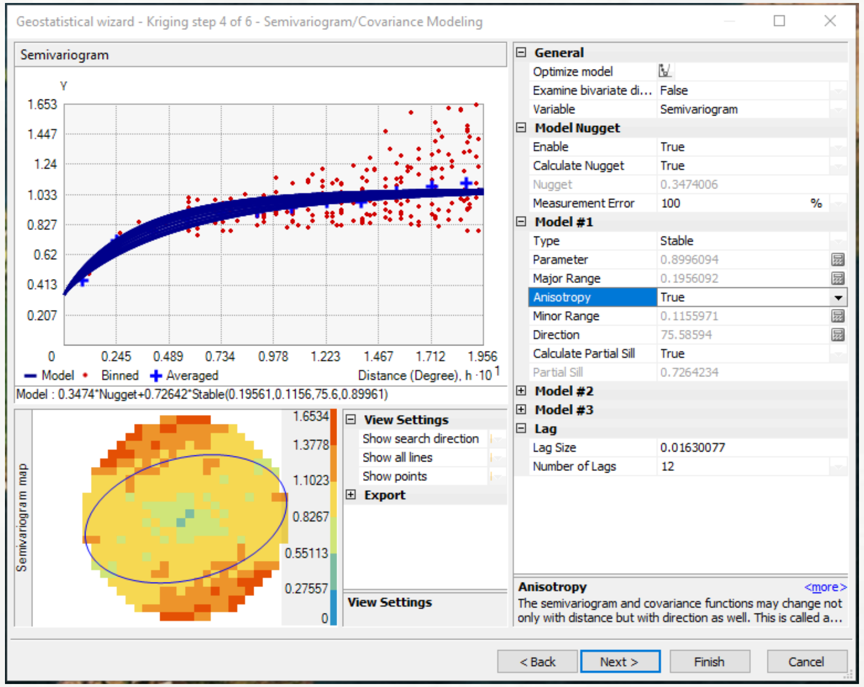
Map 2



Map 3

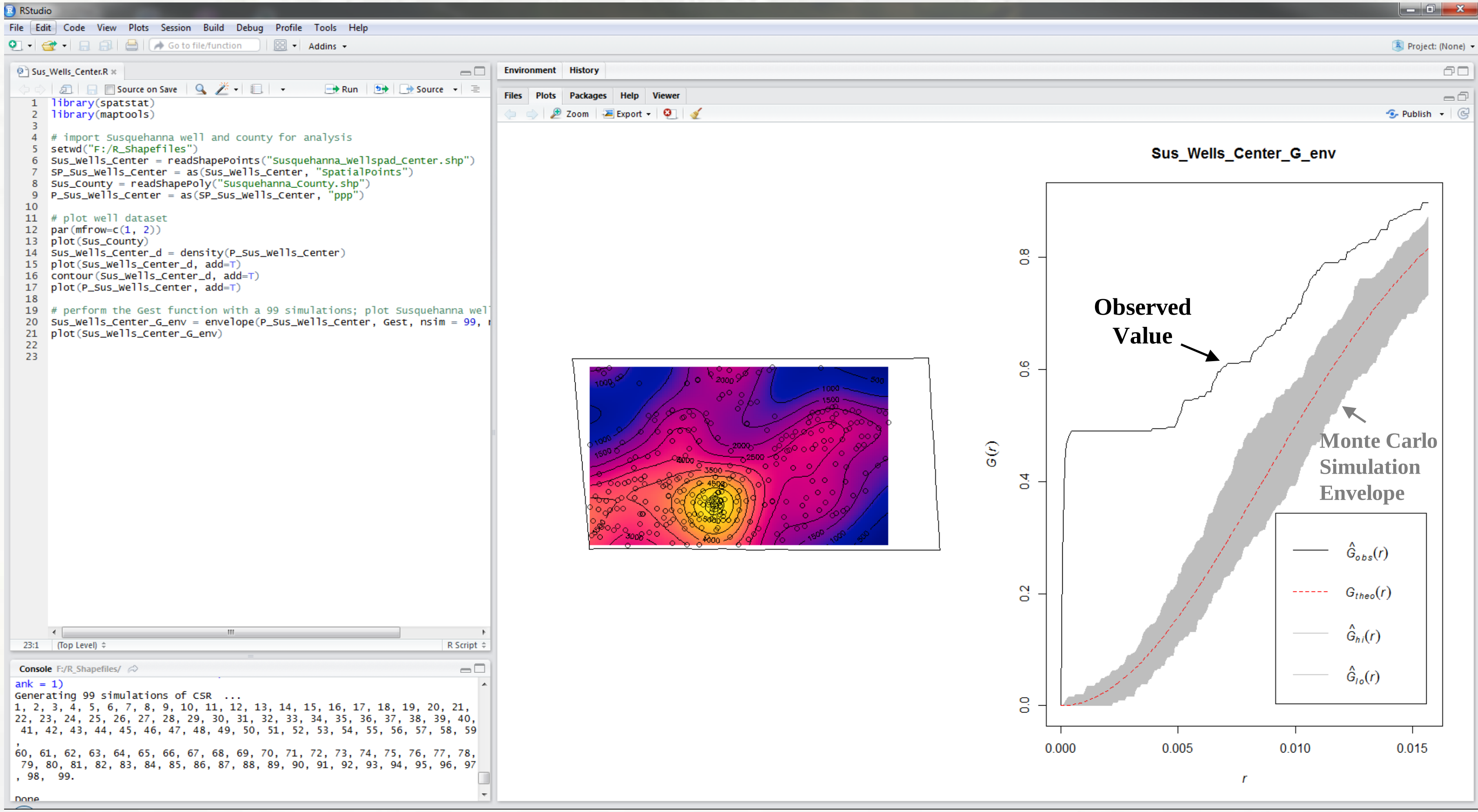
Process 2: Well Production Data Analysis

- Perform kernel density analysis and Monte Carlo Simulations of the G-function() using R to understand the point pattern of producing wellpads.
- Plot well production by formation thickness and depth using GeoDa.
- LISA analysis for MCF production by formation using GeoDa.
- Kriging to locate and predict areas that are most productive by formation.



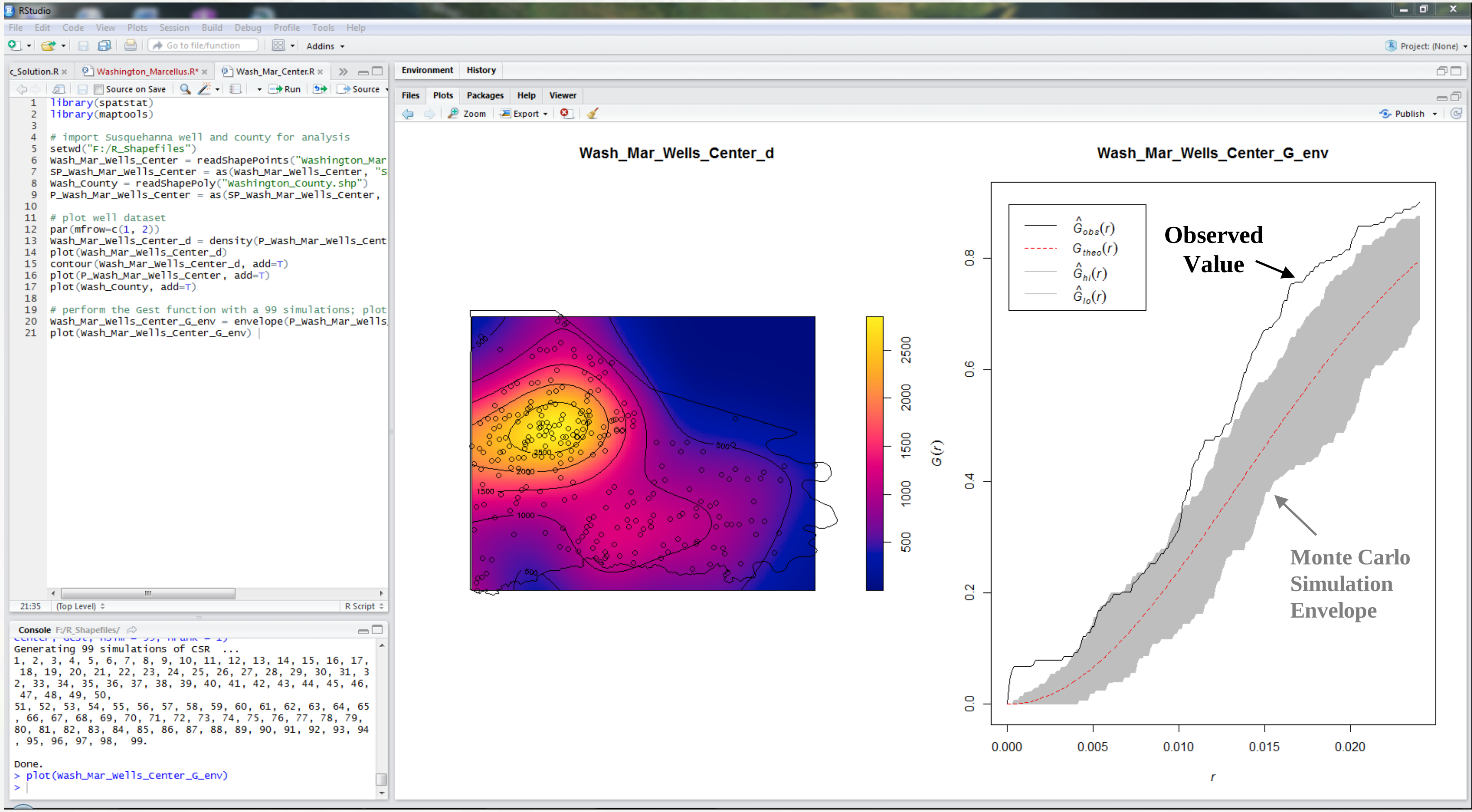
Monte Carlo Simulation – Susquehanna County Marcellus Wellpad Center

- The plot on the left is a kernel density analysis.
- Plot on the right is the output of the G-function(), which estimates the nearest neighbor distance distribution function G(r) from the point pattern.
- Observed values (black line) remained above and outside the 99 Monte Carlo simulation envelope (gray area) for all r values on the plot.
- We can conclude for the whole range of the plot, the observed pattern is **more clustered** than we would expect to be generated by IRP/CSR.

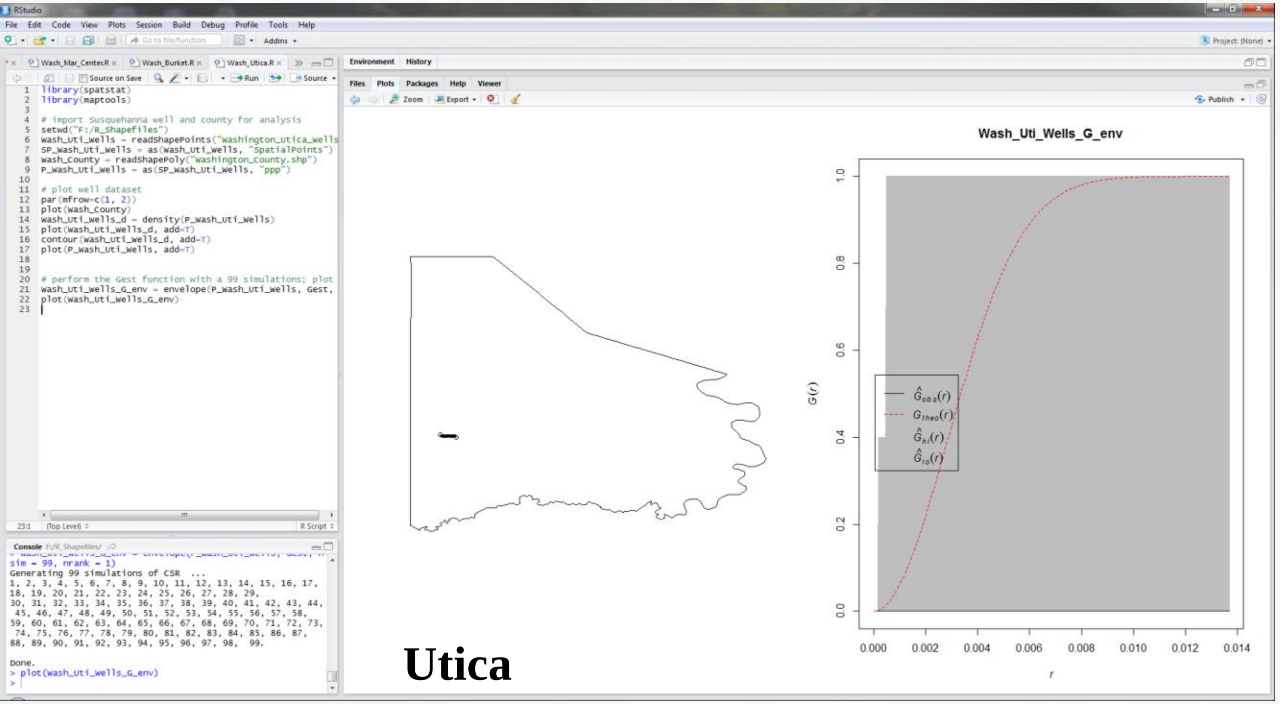


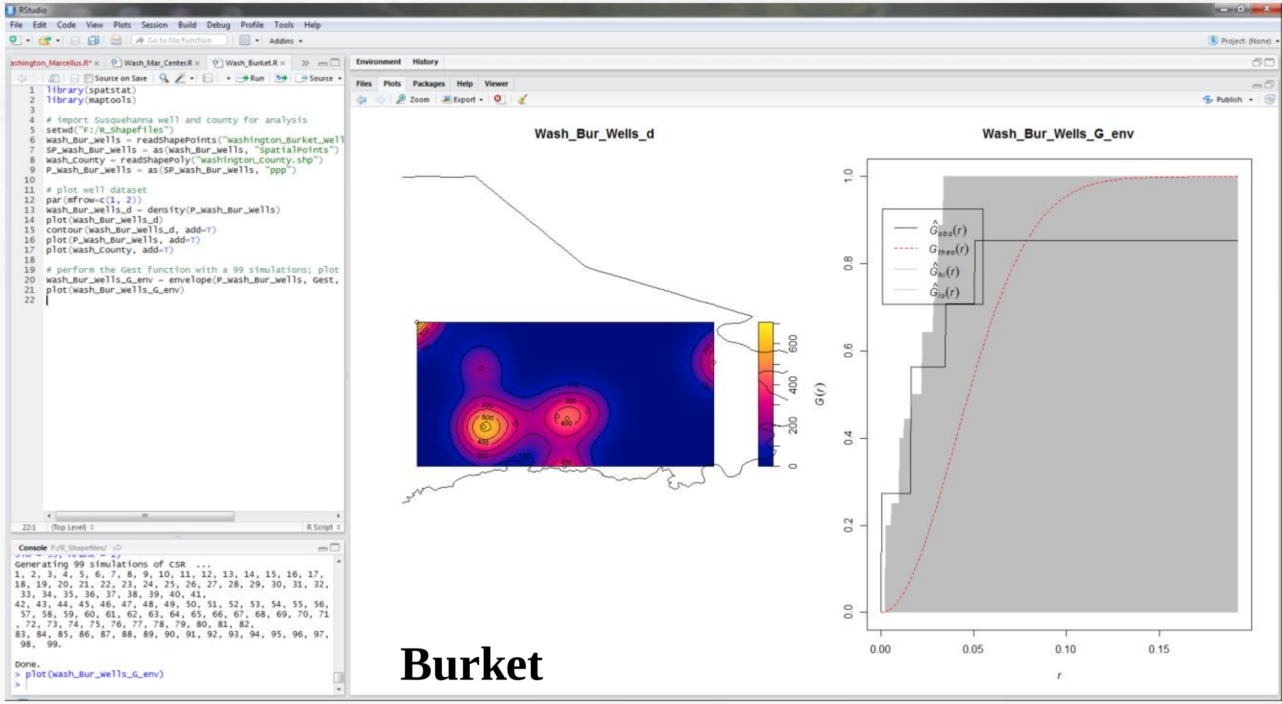
Monte Carlo Simulation – Washington County Marcellus Wellpad Center

- The plot on the left is a kernel density analysis.
- Plot on the right is the output of the G-function(), which estimates the nearest neighbor distance distribution function G(r) from the point pattern.
- Observed values (black line) remained above and outside the 99 Monte Carlo simulation envelope (gray area) for a majority of the plot.
- We can conclude for r values from 0 – 0.005 and > 0.010 the observed pattern is more clustered, while r values from 0.005 – 0.010 are spatially random.



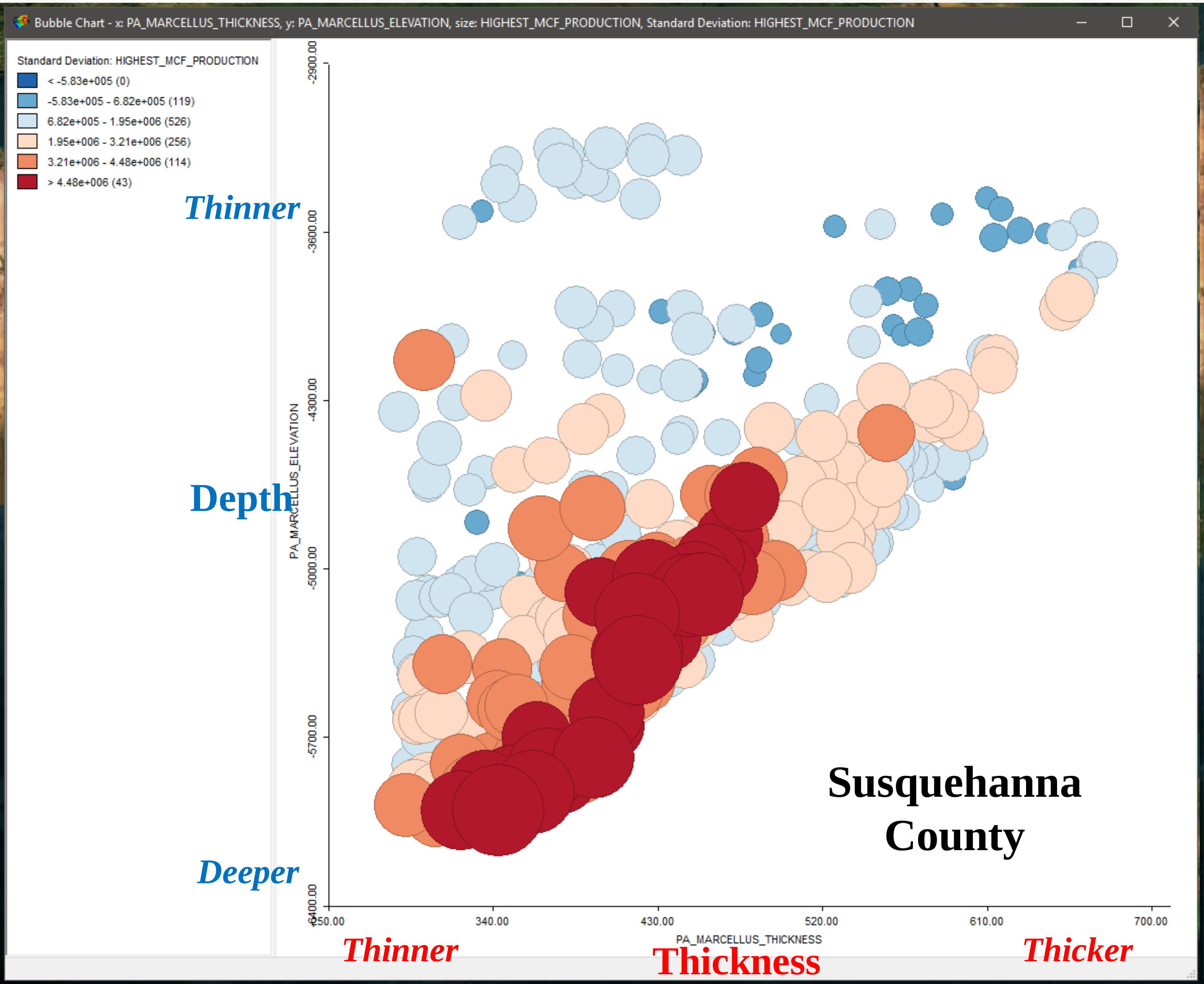
Monte Carlo Simulations – Washington County

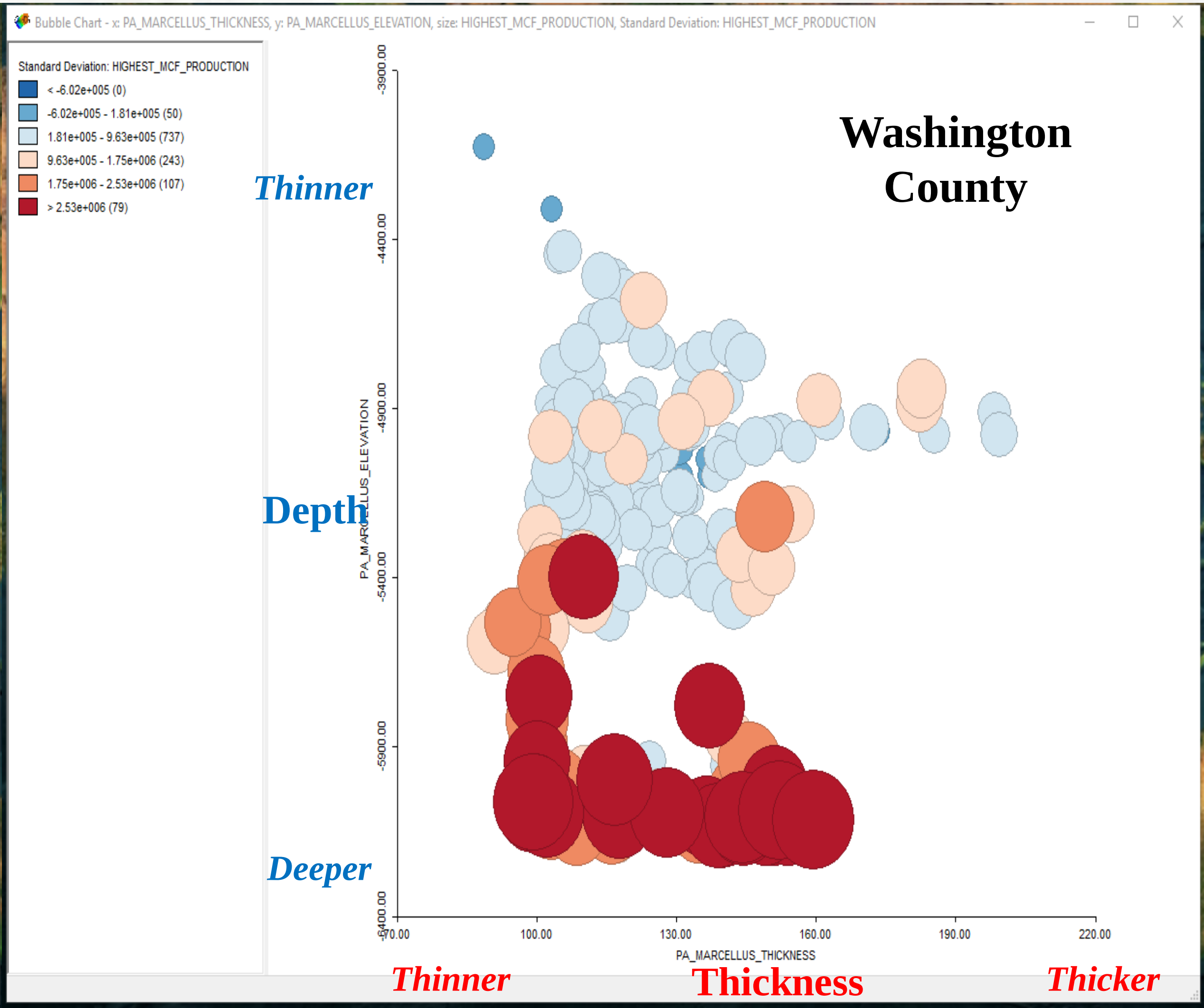




Not enough data for Utica or Burket formations to make proper conclusions on point pattern.

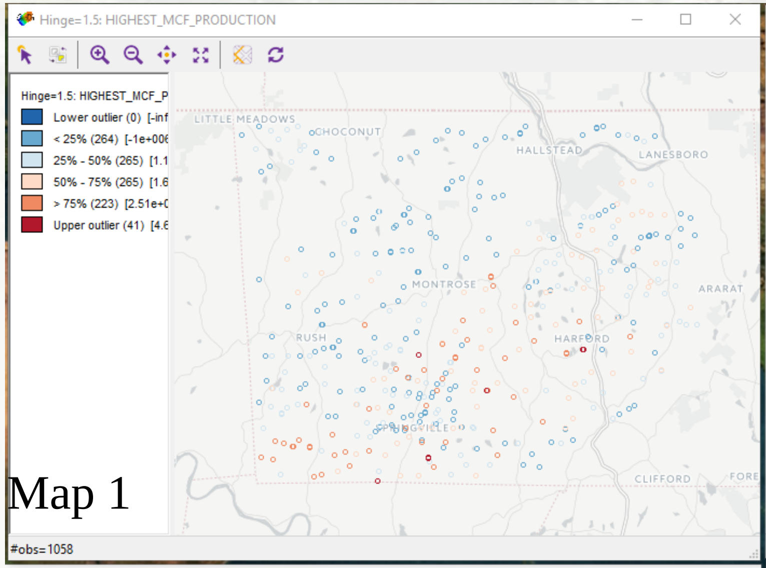
Well Production by Marcellus Formation Thickness and Depth

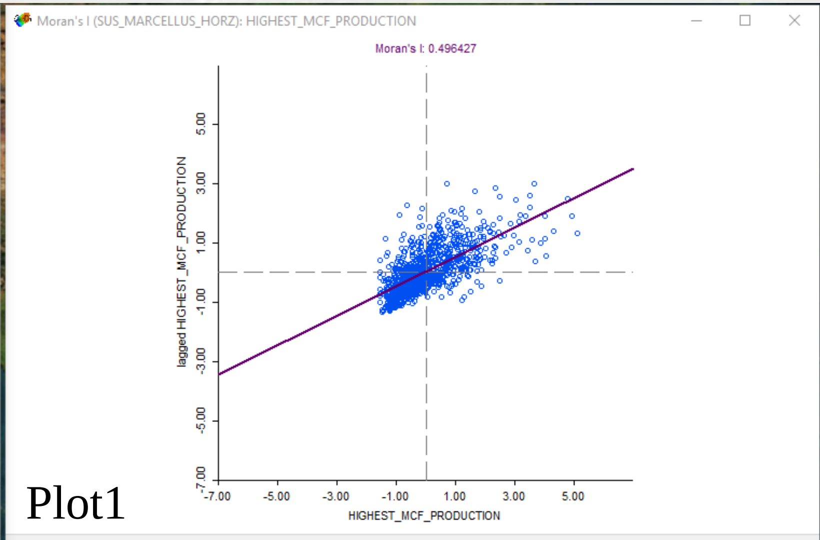


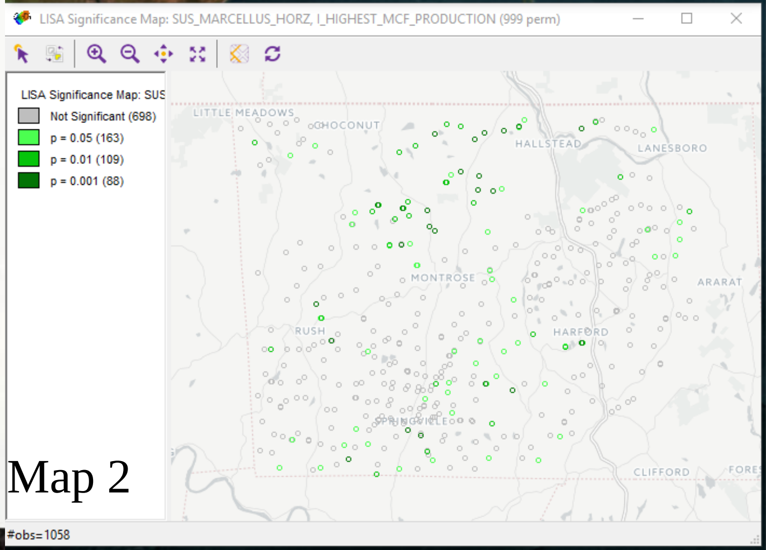


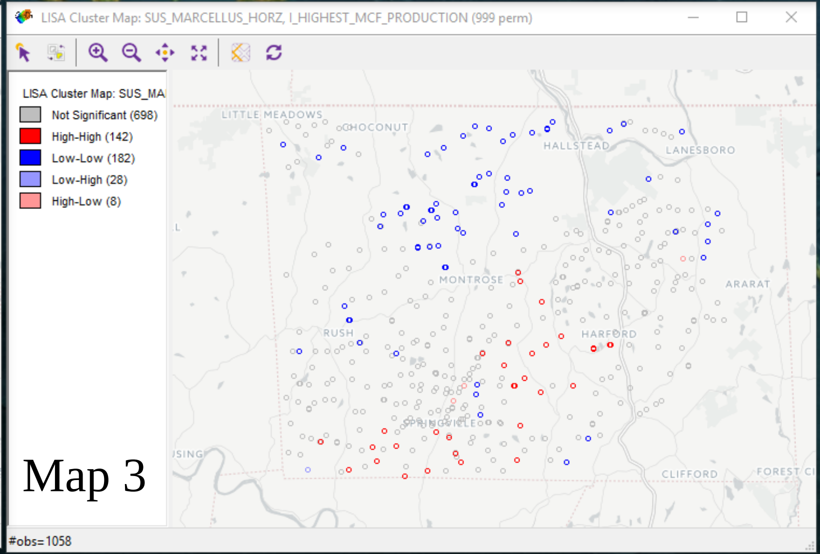
LISA Analysis of Susquehanna Co. Marcellus MCF Production

- Map 1 is a box map of the **Highest Annual MCF Production by Susquehanna Co. Marcellus Shale Well.**
- Plot 1 is a Moran’s I scatterplot
  - Moran’s I = 0.496
  - Strong positive spatial autocorrelation
- Map 2 is the LISA significance map.
  - Darker shades of green are wells that contribute to the local significance, while areas in white are non-significant locations.
- Map 3 is the LISA cluster map.
  - Shows wells that significantly contributed to the positive autocorrelation.
- **Dismiss spatial randomness** and can locate and characterize the clusters of wells.



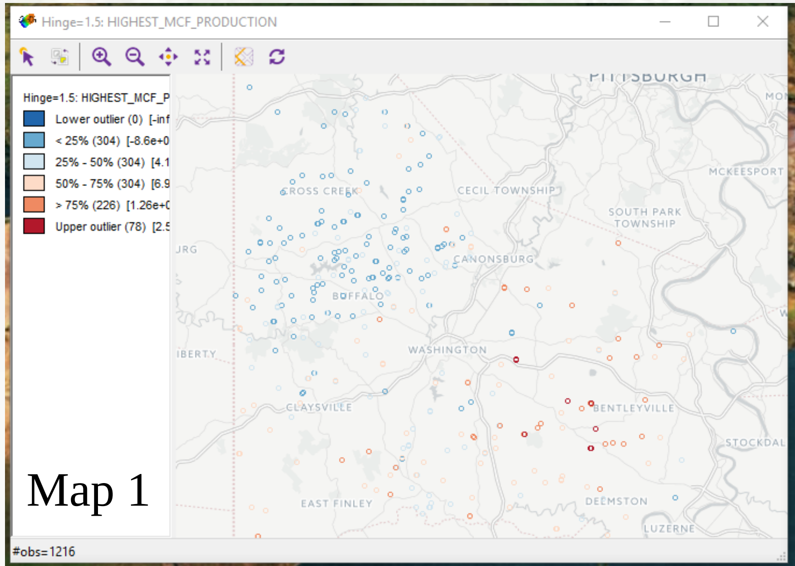


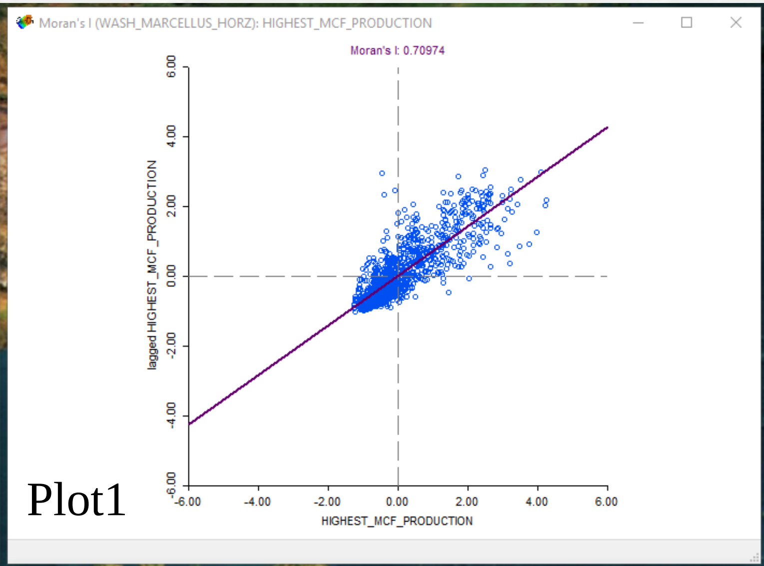


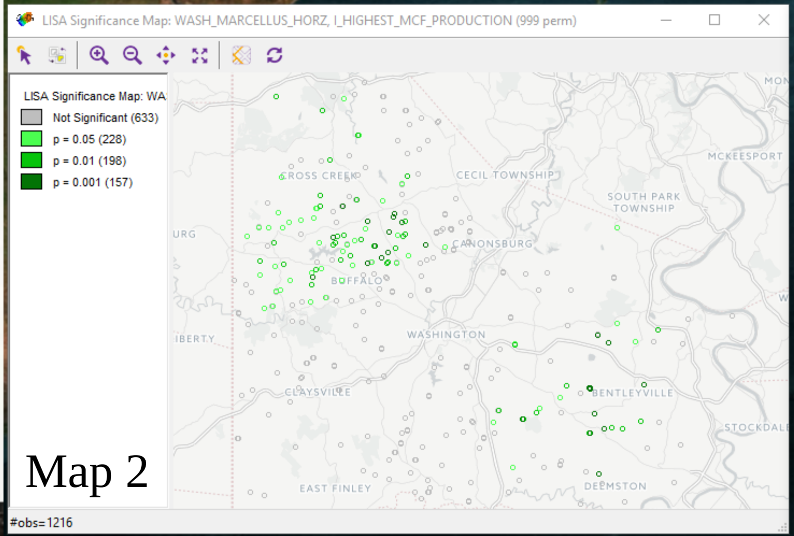


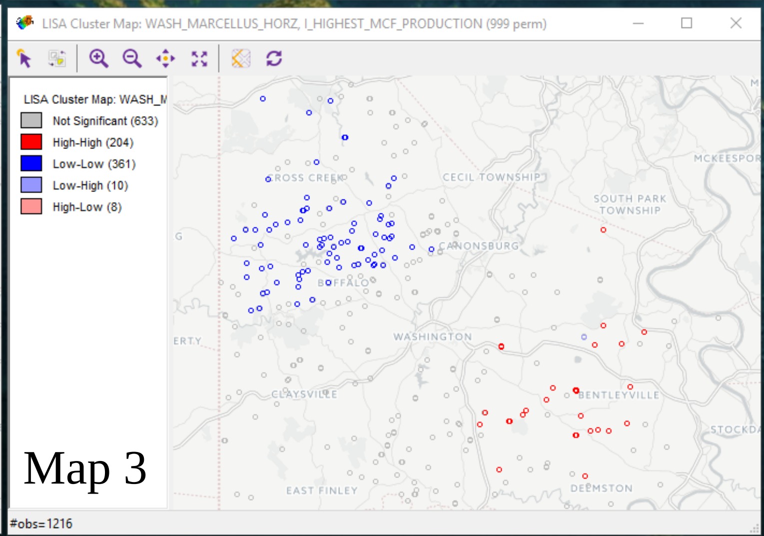
LISA Analysis of Washington Co. Marcellus MCF Production

- Map 1 is a box map of the **Highest Annual MCF Production by Washington Co. Marcellus Shale Well.**
- Plot 1 is a Moran's I scatterplot
  - Moran's I = 0.710
  - Strong positive spatial autocorrelation
- Map 2 is the LISA significance map.
  - Darker shades of green are wells that contribute to the local significance, while areas in white are non-significant locations.
- Map 3 is the LISA cluster map.
  - Shows wells that significantly contributed to the positive autocorrelation.
- **Dismiss spatial randomness** and can locate and characterize the clusters of wells.



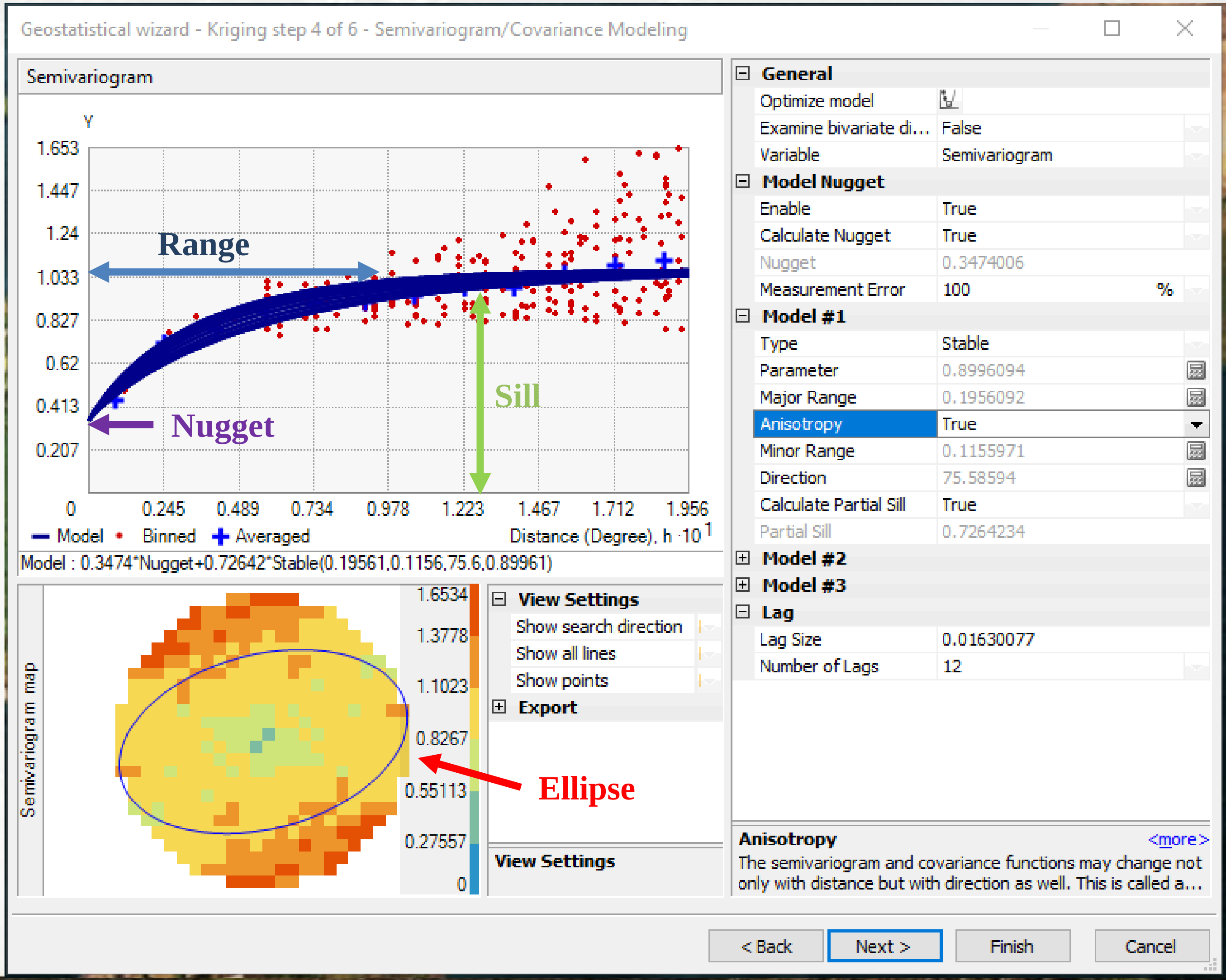




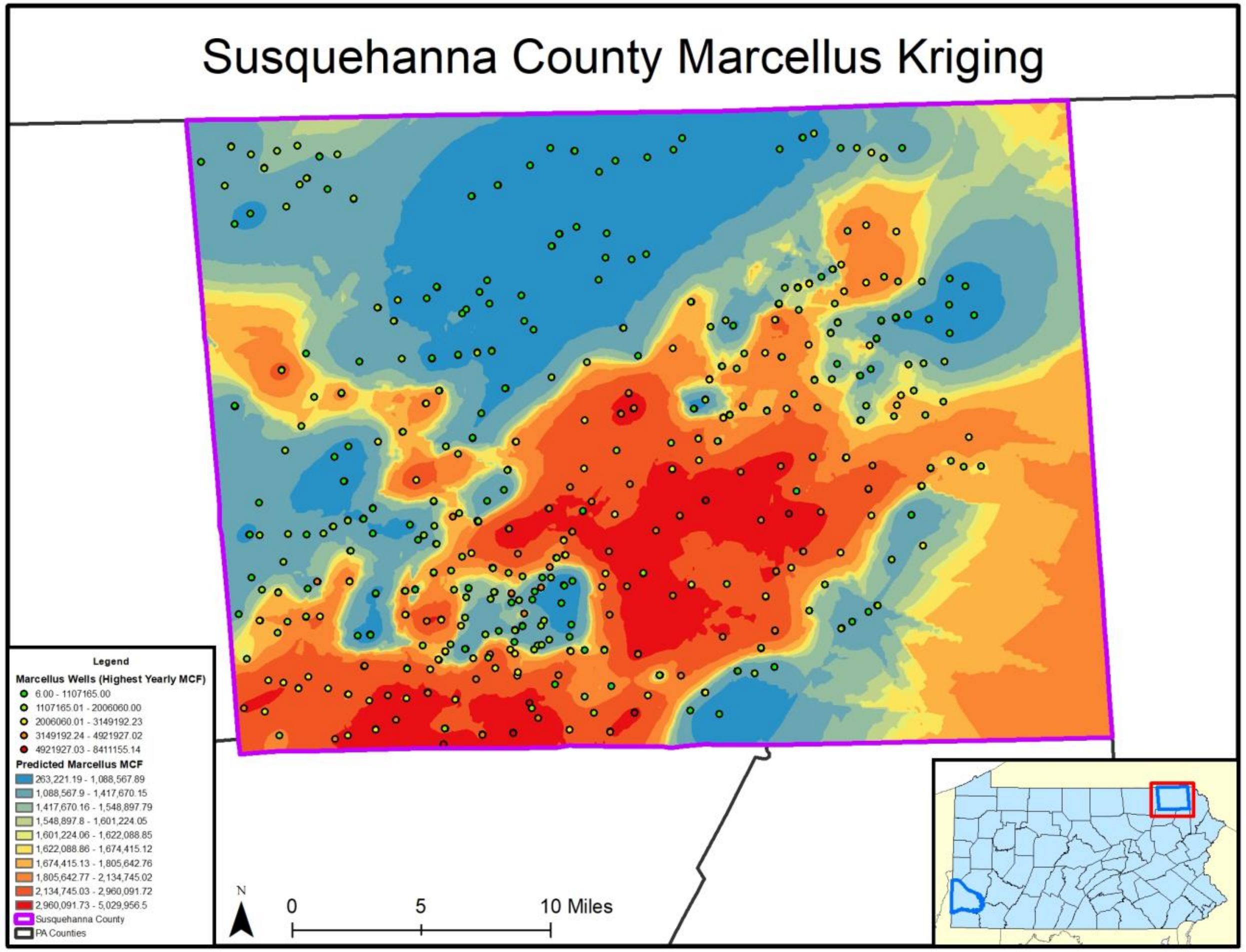


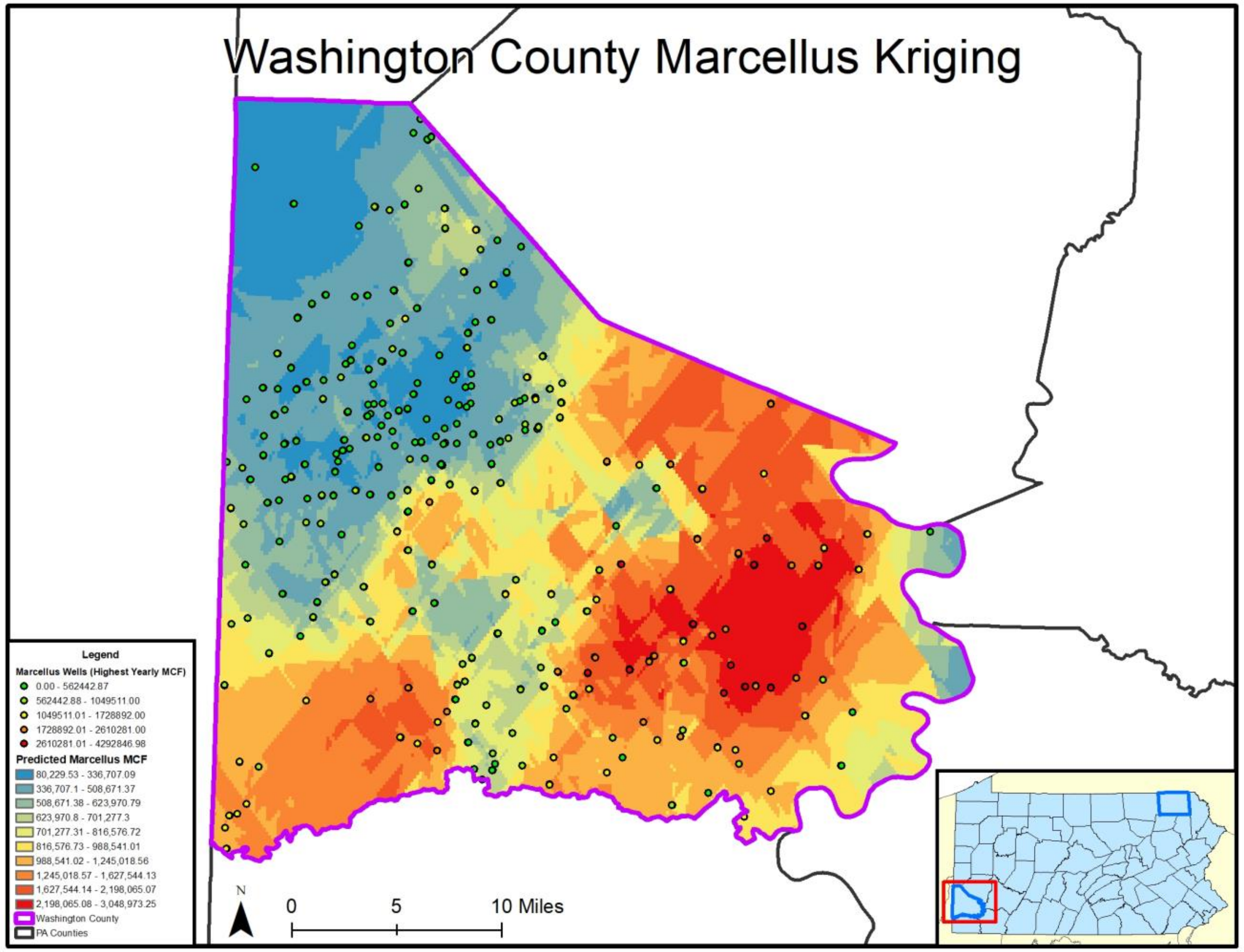
Marcellus MCF Prediction - Anisotropic Semivariogram

- ArcGIS Geostatistical Analyst Extension
- Kriging assumes that the variation in a surface can be broken down into **three main components**: drift, local spatial autocorrelation, and random stochastic variation.
  - **Still:** The semivariance value or amplitude along the y-axis where the variogram levels off **(Drift).**
  - **Range:** The distance along the x-axis were the semivariogram reaches the sill value. For distances that are greater than the range, points are likely to be similar and **autocorrelation** is essentially zero.
  - **Nugget:** The value at which the function meets the y-axis. Oftentimes this value is not at the origin of the graph, therefore, we can interpret the difference as the measure of **random stochastic variation.**
- **Anisotropy** is a property of a spatial process where spatial dependence (autocorrelation) changes with both the distance and the direction between two locations.



Marcellus MCF Prediction - Anisotropic Semivariogram

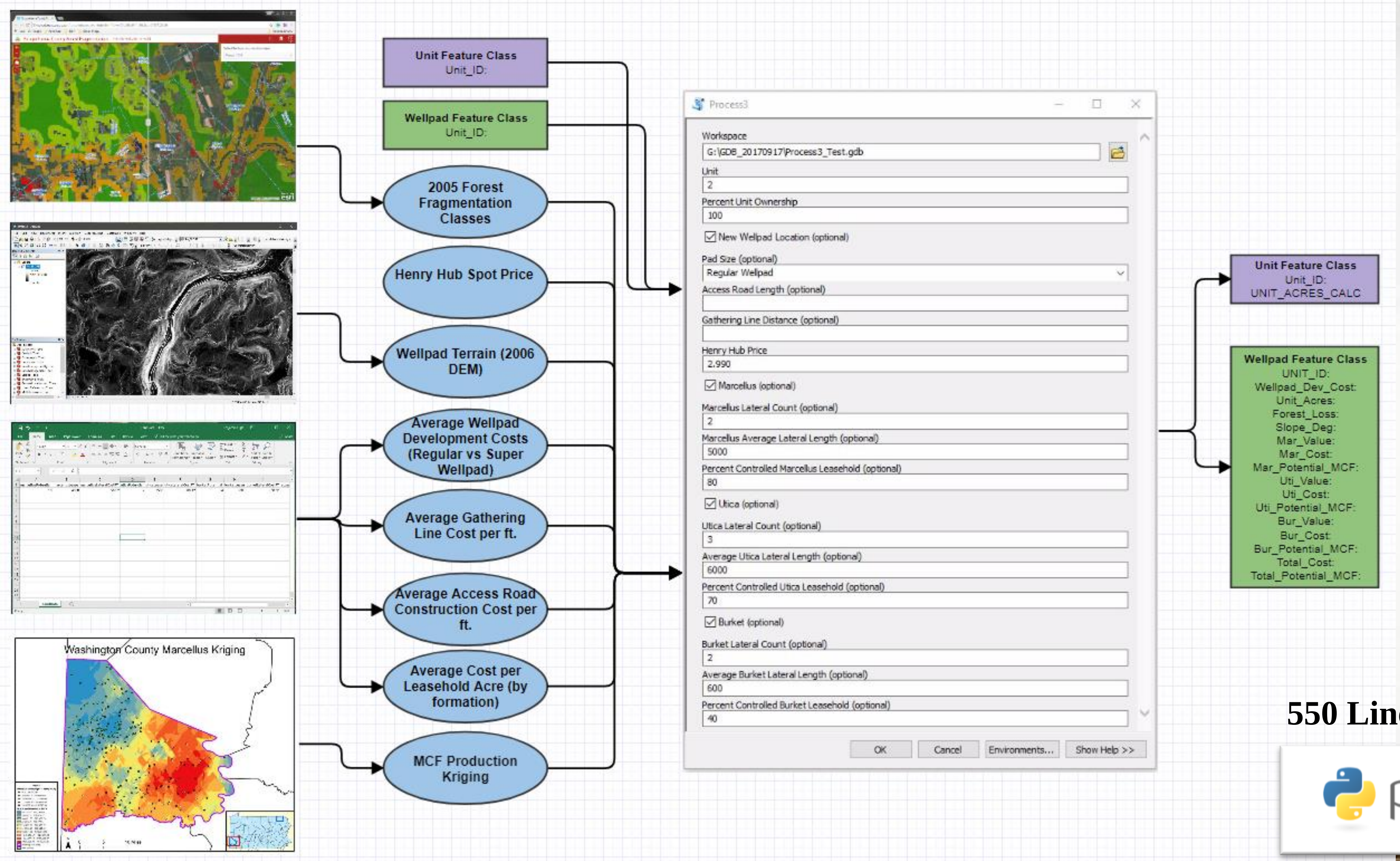




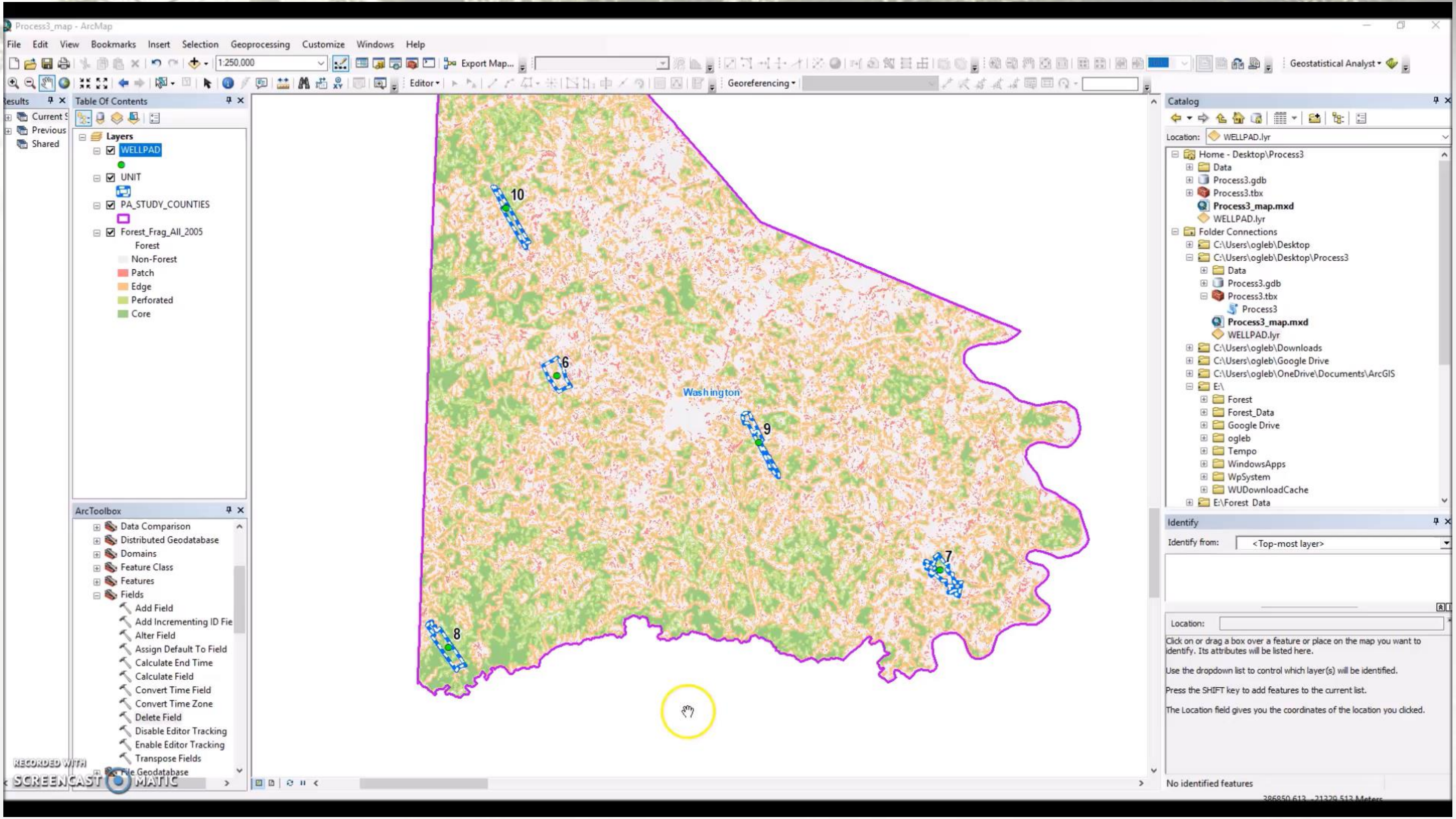
Process 3: Develop Tool based on Findings

- The tool was designed by identifying system requirements in the needs assessment phase (June 2017).
- The prototype was initially developed using Balsamiq.
- Scores the viability and profitability of a well pad location.

Process 3: Develop Tool based on Findings



550 Lines of Code!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Use the dropdown list to control which layer(s) will be identified.
Press the SHIFT key to add features to the current list.
The Location field gives you the coordinates of the location you clicked.
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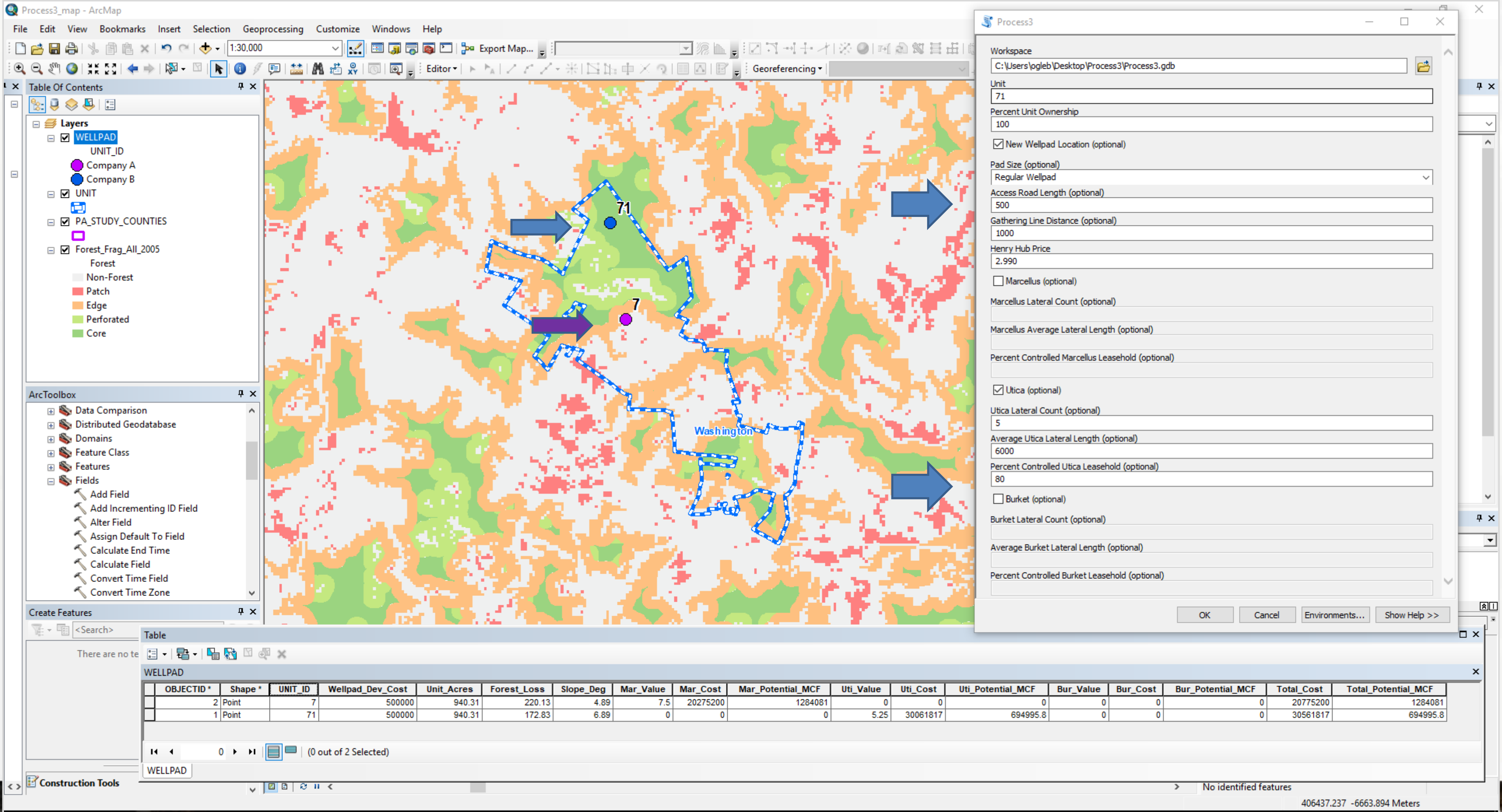
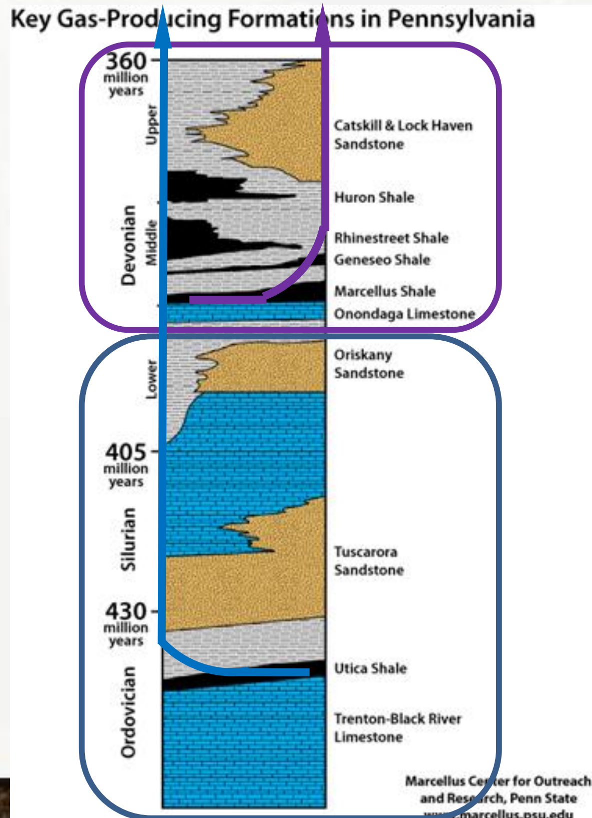
Process 3 Example

Company A (3rd Party):
- 100% Marcellus leasehold
- Existing wellpad 7
- 20% Utica leasehold

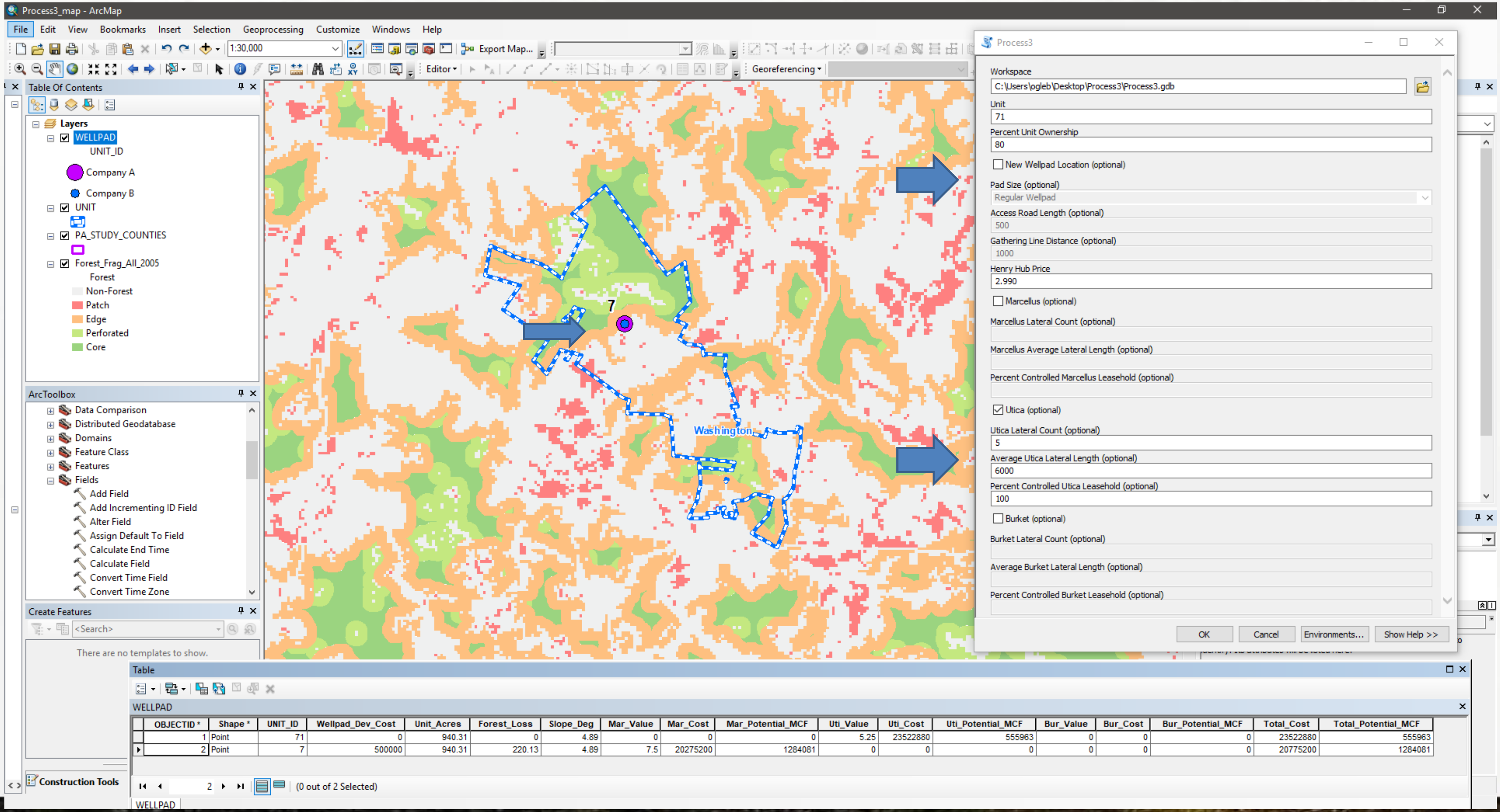
Company B (CNX):
- 80% Utica leasehold
- No existing wellpad
- Proposed well 71



OBJECTID *	Shape *	UNIT_ID	Wellpad_Dev_Cost	Unit_Acres	Forest_Loss	Slope_Deg	Mar_Value	Mar_Cost	Mar_Potential_MCF	Uti_Value	Uti_Cost	Uti_Potential_MCF	Bur_Value	Bur_Cost	Bur_Potential_MCF	Total_Cost	Total_Potential_MCF
2	Point	7	500000	940.31	220.13	4.89	7.5	20275200	1284081	0	0	0	0	0	0	20775200	1284081
1	Point	71	500000	940.31	172.83	6.89	0	0	0	5.25	30061817	694995.8	0	0	0	30561817	694995.8



Process 3 Example



Company A (3rd Party):

- 100% Marcellus leasehold
- Existing Wellpad location (Well 7)
- 20% Utica leasehold

Company B (CNX):

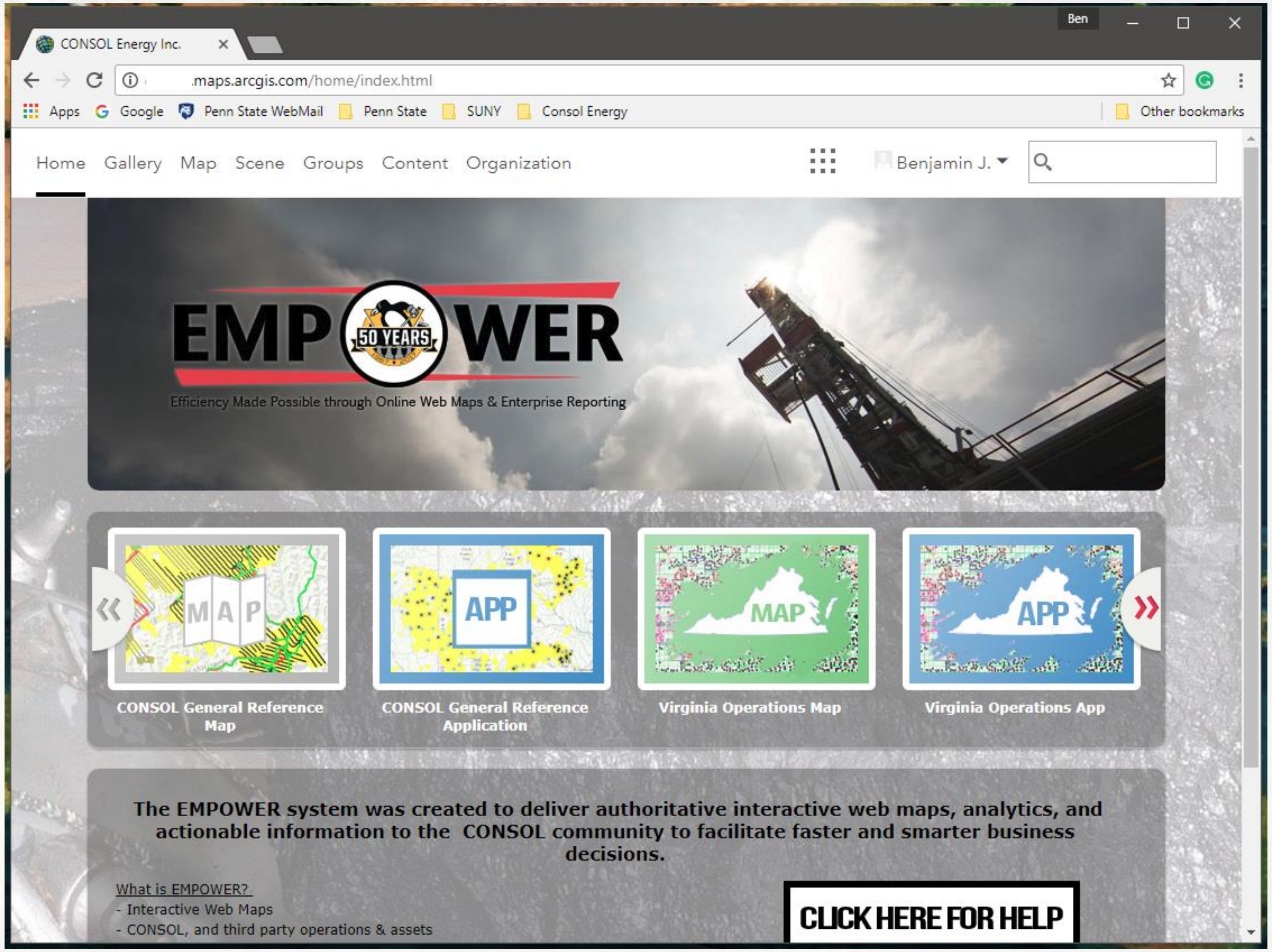
- 80% Utica leasehold
- Use Company A existing wellpad location

Company B Results:

- 589,085 less yearly predicted MCF production.
- **~7 million** less on cost!
- An estimated **172.83 forested acres** will not be fragmented!

Sharing Developed Tools and Datasets

- Datasets is shared on CNX's ArcGIS Online organizational account.
- A Web mapping application was developed to display and share results using Esri Web AppBuilder.
- The tool (Process 3) will be shared as a geoprocessing REST Service.



Outcomes

- Forest fragmentation was observed to be more prevalent in areas of oil & gas activity.
- Oil & gas activities is not the only cause of forest fragmentation.
- Areas where wellpads, producing from multiple shale formations, can be more productive and result in less overall forest fragmentation.
- If gas exploration companies work together (by forming joint owner agreements or trading leasehold so that only one company has full ownership at all depths) a drilling unit will be more efficient and result in less overall forest fragmentation.
- Regions, where drilling units were once economically viable, will be less attractive today because of the lower natural gas price.

Challenges

- Data is difficult to source
  - Pipeline data
  - Company access roads to well pads
- Landscape Fragmentation Tool (LFT) v 2.0 did not run properly.

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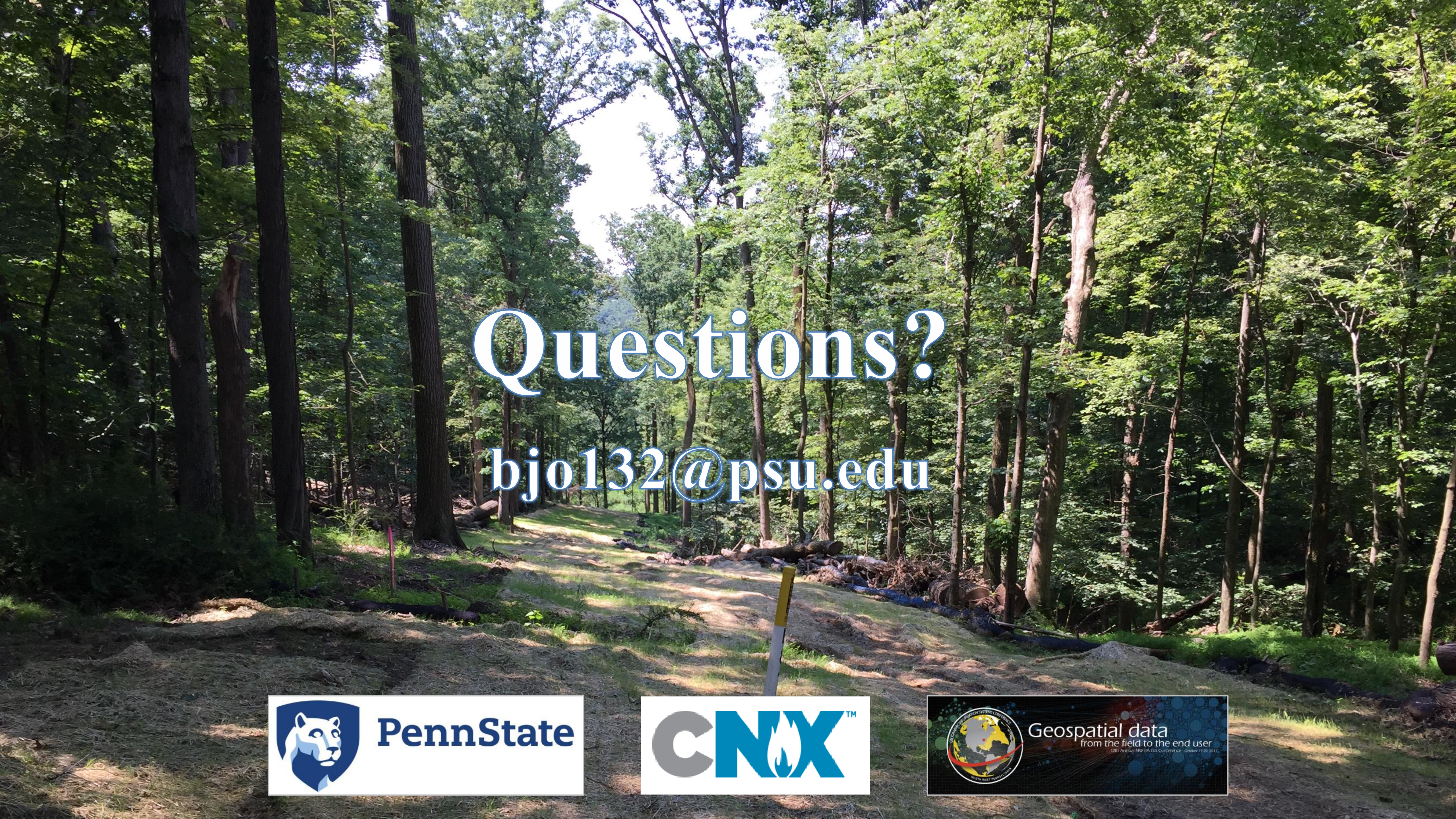

Questions?
bjo132@psu.edu
PennState
CNX
Geospatial data
from the field to the end user